Resonance

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What Can the Answer be ? ❖ Adaptive Mutation ❖ Journey through Genius ❖ Genetics to Genetic Algorithms ❖ New Orbital Hybridization Schemes for Metal Hydrides

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Editorial

N Mukunda, Chief Editor

One of our avowed aims, always in our minds, is to encourage students, teachers and others familiar with one area of science to read about other areas distant from their own. We consciously try to include material in each issue that will serve this purpose.

Madhav Gadgil's series on 'Life – Complexity and Diversity' takes up the problem of scales of diversity encountered in the living world. Here is a prime example where an outsider to biology – say a mathematician or a physicist – needs some key concepts or viewpoints which will act as guides in assimilating facts, ordering them into a coherent pattern, and in avoiding the feeling of being swamped by detail. Gadgil's statement that "Diversity of life is therefore best viewed in two major contexts: diversity of hereditary material amongst members and the same species, and the diversity of species within a biological community" serves this purpose admirably and helps us grasp the basic ideas involved. To a student of biology it must be common knowledge that the number of extant life forms – species – today is anywhere between fifteen million and a hundred million; of this only a million and a half have so far been recorded in the literature. Gadgil also describes the sense in which we humans share a very high percentage of genetic material with our nearest relatives – chimpanzees, gorillas, old world monkeys, and orangutans – in each case around ninety five percent or more. And yet we seem to be so different in appearance and abilities. As the French say in another context – 'Long live the difference'!

Diversity of life is therefore best viewed in two major contexts: diversity of hereditary material amongst members of the same species, and the diversity of species within a biological community.

We are privileged to feature Harish-Chandra in this issue – with a portrait on the back cover and a short 'Article in a box'

by Rajat Tandon. Harish-Chandra was the greatest Indian mathematician since Srinivasa Ramanujan. Though he grew up in India, and began his research career as a theoretical physicist working with Homi Jehangir Bhabha at the Indian Institute of Science in Bangalore during 1943–45, the rest of his professional career and his blossoming into a mathematician of world stature took place in the West. And yet, quoting from his daughter Premala Chandra: "Though he spent almost all of his professional life abroad, culturally my father was always very deeply rooted in India." Ramanujan's name has long been a household word; Harish-Chandra deserves no less. Appreciations of his work and the monumental character of his achievements by R P Langlands and V S Varadarajan appear elsewhere in this issue. His only collaborator Armand Borel said this of him some time ago: "Harish-Chandra was a highly principled man, for whom one's life had to have a purpose. In his view, the main one of his own was no doubt to prove the hardest and the most fundamental theorems accessible to him. ... Underlying this tremendous productivity were very strict, almost ascetic, discipline and routine... The sense of purpose Harish gave to his life had some spiritual, even religious underpinning. His religion was not a traditional one with the usual paraphernalia of stories, rituals, prayers and direct intervention of a personal god. Rather it was an abstract, philosophical level, a yearning for some universal principle, transcending our lives, which would give sense to the universe". To very few of us is it given to be able to even appreciate the work of such gifted individuals, leave alone to reach such heights ourselves. And yet we all need heroes – verily the salt of the earth – from whom to derive the inspiration to reach beyond ourselves.

"Though he spent almost all of his professional life abroad, culturally my father was always very deeply rooted in India"
— on Harish-Chandra by his daughter

Harish-Chandra

Harish-Chandra was born in Kanpur on the 11th of October 1923 to Chandrakishore and Chandrarani. The men in the family were professionals (lawyers, engineers), and on his mother's side, the women had obtained convent education even during the last century. Chandrakishore was an irrigation engineer who spent much of his time in the districts of U.P. Influenced by the times, he became a staunch Gandhian and dropped his surname because of his opposition to caste. Harish-Chandra initially studied with private tutors until the age of nine, when he was directly enrolled in the seventh class. During his childhood and youth, he liked to paint, although later he gave up painting altogether.

Contact with Prof. K S Krishnan at Allahabad University during his M.Sc. changed his future. Prof. Krishnan was quick to recognize Harish-Chandra's extraordinary mathematical skills and encouraged him to take up physics as a career. Harish-Chandra was persuaded to go to the Indian Institute of Science, Bangalore where he worked with Homi Bhabha during 1943–45. The first six months of his stay in Bangalore were spent with old friends from Allahabad, Mr and Mrs. G T Kale. It was here that he got to know their daughter Lalitha, and many years later when he returned to India on a visit in 1952, she became his wife. The war in Europe over, Harish-Chandra left for Cambridge to work with Paul Dirac. This was the genesis of a long friendship and Harish-Chandra credits Dirac with being one of the most important influences on his life. For his Ph.D. thesis Dirac suggested a study of the infinite dimensional representations of the Lorentz group. Harish-Chandra completed this work about the same time as I M Gelfand and M A Naimark in the erstwhile Soviet Union, and V Bargmann in the United States.

Harish-Chandra spent the year 1947 – 48 in the U.S.A. as Dirac's assistant. His earlier doctoral work together with a year of attending lectures by Claude Chevalley and Emil Artin — and the recipe for the conversion of Harish-Chandra from a physicist to a mathematician was complete. He always regarded physics with a certain amount of awe and claimed that you needed to have a sixth sense to be a successful physicist, something he thought he lacked. He preferred the unfettered freedom of mathematics.

For the next 15 years Harish-Chandra was at Harvard, Princeton or Columbia. There was a break of a year in 1952–53 which he spent at the Tata Institute of Fundamental Research, briefly flirted with but then abandoned the idea of returning to India. During these years he was building the monument for which he is famous, the general theory of semi-simple Lie groups and the construction of the Plancherel measure for such groups. He became a professor at the Institute for Advanced Study, Princeton in 1963 and he announced that he had the general

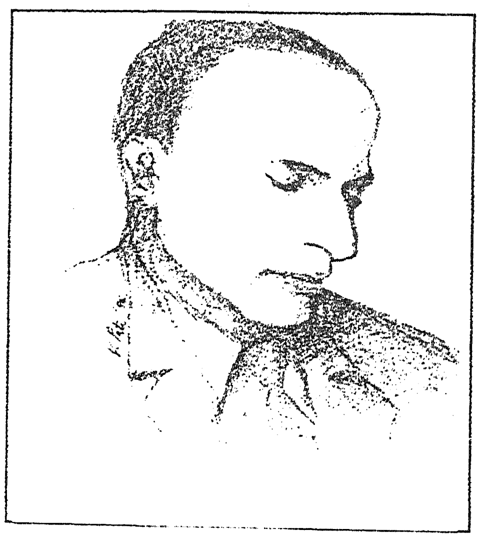
Plancherel formula at the International Congress of Mathematicians, Moscow 1966. *Then* followed several long papers to support his claim. He then turned his attention to reductive groups over the *p*-adics because "there is no reason why the reals should be more important than any other completion of the rationals." In the words of R P Langlands "Harish-Chandra was one of the outstanding mathematicians of his generation, an algebraist and analyst, and one of those responsible for transforming infinite-dimensional group representation theory from a modest topic on the periphery of mathematics and physics into a major field central to contemporary mathematics." Harish-Chandra worked incredibly hard, often all night through, night after night. This took its toll and his health deteriorated. He published just one joint paper with A Borel in 1960 at the time of his first serious illness.

Harish-Chandra won the Coles Prize of the American Mathematical Society in 1954, the Srinivasa Ramanujan Medal of INSA in 1974, became a Fellow of the Royal Society in 1973 and a member of the National Academy of Sciences, U.S.A. in 1981. He was made the IBM von Neumann Professor at the Institute for Advanced Study in 1968.

During a talk on the 80th birthday celebration for Dirac, Harish-Chandra said "I have often pondered over the roles of knowledge or experience on the one hand, and imagination or intuition, on the other, in the process of discovery. I believe that there is a certain fundamental conflict between the two and knowledge, by advocating caution, tends to inhibit the flight of imagination. Therefore a certain naiveté, unburdened by conventional wisdom, can sometimes be a positive asset. I regard Dirac's discovery of the relativistic equation of the electron as a shining example of such a case." Harish-Chandra, like most creative mathematicians, believed in the dictum "Mathematics is like music; you must practise it in order to be able to teach it."

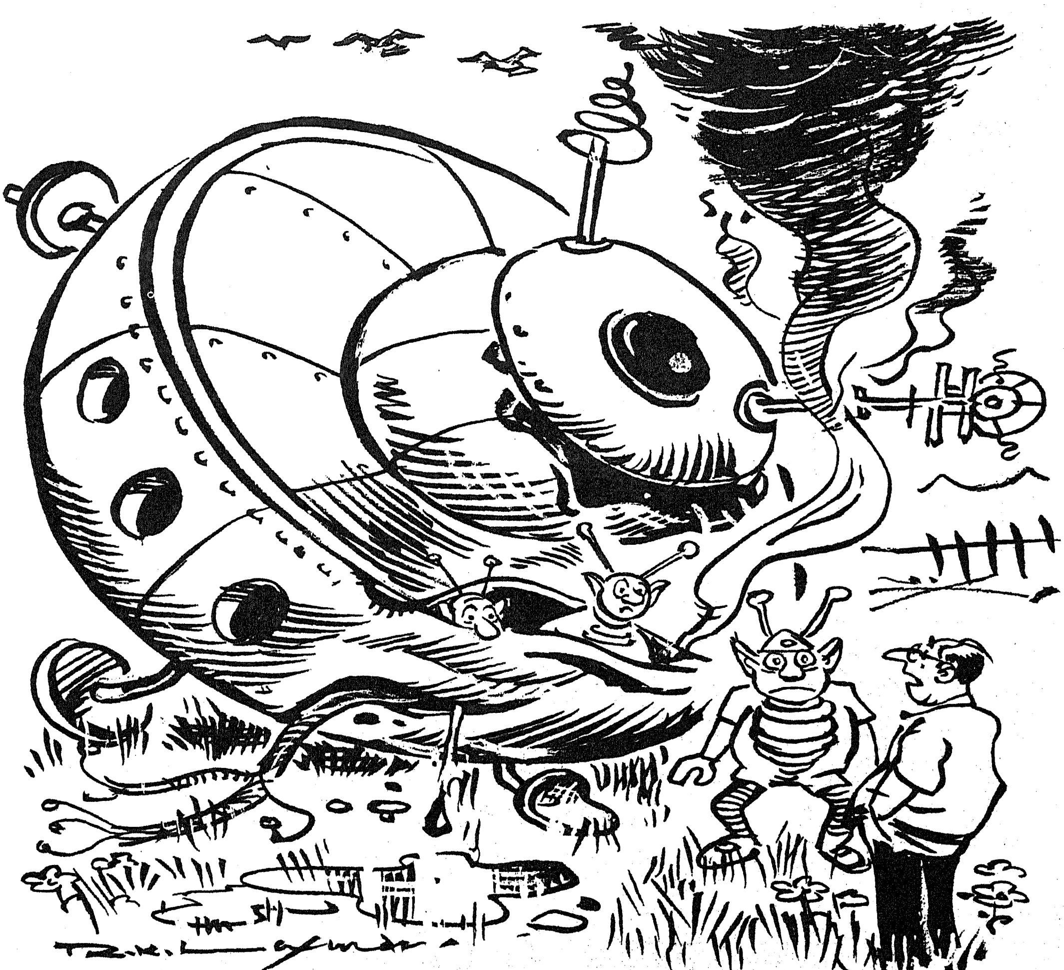
Harish-Chandra died on 16 October 1983.

R Tandon



Science Smiles

R K Laxman



I am sorry ! This is the problem we on earth here have to face; bird menace. They hit aircrafts.

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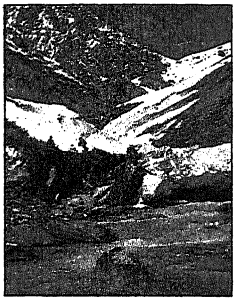

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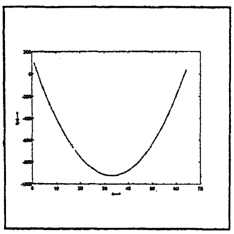

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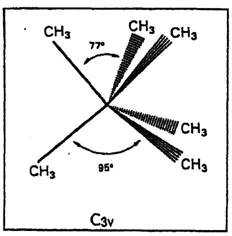

SERIES ARTICLES

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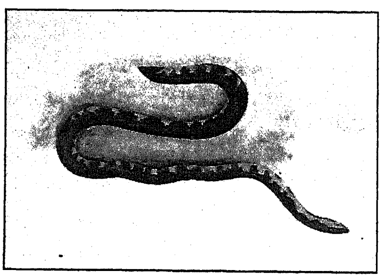

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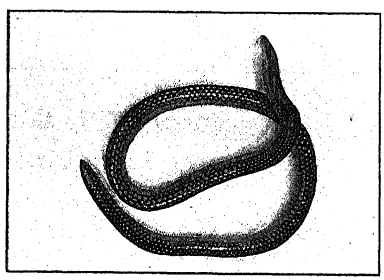

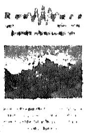

Front Cover

Melting of snow : Birth of Himalayan river in Kumaun (at Milam glacier).

Back Cover

Harish-Chandra (1923 – 83)
(Illustration by Prema Iyer).

DEPARTMENTS

What can the Answer be?

1. Elementary Vector Analysis

V Balakrishnan

V Balakrishnan teaches Physics at the Indian Institute of Technology, Madras. His research involves strong mathematics coupled to intereosting physical situations such as the mechanical properties of solids, with randomness and chaos being frequent themes. Apart from being regarded highly as a teacher and expositor, he has wide interests outside Physics as well.

A very useful approach in tackling scientific problems is to ask what the answer could possibly be, under the constraints of the given problem. In the first part of this series, this approach is illustrated with some examples from elementary vector analysis.

Scientific problems are very often first solved by a combination of analogy, educated guesswork and elimination – in short, 'insight'. The refinements that come later do not make this earlier process less important. Rather, they generally serve to highlight its value.

Techniques such as dimensional analysis, scaling arguments and order-of-magnitude estimates, as well as checks based on limiting values or limiting cases are part of the armoury

There is no graded set of lessons by which one progressively gains insight. However, a profitable line of approach is to ask, at each stage, what the answer to a problem could possibly be, subject to the conditions involved. Techniques such as dimensional analysis, scaling arguments and order-of-magnitude estimates, as well as checks based on limiting values or limiting cases are part of the armoury in this mode of attack. In this set of three articles, I shall use a series of examples mainly in *elementary vector analysis* in an attempt to provide a flavour of this approach.

An Example from Algebra

To set the stage, let us begin with an example in elementary algebra. Consider the determinant

$$\Delta\,(x_1, x_2, x_3) = \begin{vmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ x_1^2 & x_2^2 & x_3^2 \end{vmatrix} \qquad (1)$$

It is straightforward, of course, to find Δ explicitly by expanding the determinant. But the point I wish to make here is that Δ can be evaluated almost by inspection, if we note the following facts:

- Multiplying each of x_1, x_2 and x_3 by some number λ multiplies the value of Δ by λ^3. Thus Δ is a *homogeneous* function of degree 3.
- Δ vanishes if any two of the x's are equal. Therefore, regarded as a function of x_1, Δ is quadratic with factors $(x_1 - x_2)$ and $(x_1 - x_3)$; and similarly for x_2 and x_3.
- Δ changes sign if any two of the x's are interchanged.

Combining these points, we conclude that Δ *must* be given by

$$\Delta\,(x_1, x_2, x_3) = C(x_1 - x_2)\,(x_2 - x_3)\,(x_3 - x_1), \qquad (2)$$

where C is some numerical constant.

- To find the constant C, we have only to look at a simple case, e.g., $x_1=0$, $x_2=1$, $x_3=2$. This gives $C=1$. (Alternatively, match the term $+x_2\,x_3^2$ obtained by multiplying together all the diagonal elements of the determinant with the corresponding term $+Cx_2\,x_3^2$ on the right in equation (2)). Finally, therefore, we have

$$\Delta\,(x_1, x_2, x_3) = (x_2 - x_1)\,(x_3 - x_1)\,(x_3 - x_2). \qquad (3)$$

The factors have been written in such a way that *selecting the first term in each bracket yields the product of the diagonal elements of the determinant with the correct sign.*

What is important is that our chain of reasoning permits us to *generalize* this result to the case of the $(n \times n)$ determinant (called the Vandermonde determinant)

$$\Delta\,(x_1,\ldots,x_n) = \begin{vmatrix} 1 & 1 & \ldots & 1 \\ x_1 & x_2 & \ldots & x_n \\ \cdot & \cdot & \ldots & \cdot \\ x_1^{(n-1)} & x_2^{(n-1)} & \ldots & x_n^{n-1} \end{vmatrix} \qquad (4)$$

We can now see that Δ must simply be a product of the $n(n-1)/2$ distinct factors $(x_j - x_k)$ that can be formed from the variables $x_1,\ldots, x_n$. The *diagonal element* $+x_2\, x_3^2\, x_4^3 \ldots x_n^{n-1}$ indicates that the sign of each term in Δ is taken care of if we always maintain $j > k$ in each factor $(x_j - x_k)$. Therefore we have the general result

$$\Delta\,(x_1,\ldots,x_n) = \prod_{1 \le k < j \le n} (x_j - x_k) \qquad (5)$$

without going through a tedious calculation. This is the spirit in which we shall approach the problems that follow.

Some Vector Identities

Let us now go on to vector analysis. As the first example, we consider the derivation of the identity

$$\mathbf{a} \times (\mathbf{b} \times \mathbf{c}) = (\mathbf{a} \cdot \mathbf{c})\mathbf{b} - (\mathbf{a} \cdot \mathbf{b})\mathbf{c} \qquad (6)$$

where **a**, **b** and **c** are three arbitrary vectors (in the usual three dimensional space, say). We would like to avoid the 'brute force' method of writing out components, etc. in some

particular coordinate system. We therefore proceed as follows. Let $\mathbf{a} \times (\mathbf{b} \times \mathbf{c}) = \mathbf{d}$.

- If **a**, **b** and **c** are three general non-planar vectors in three-dimensional space, any arbitrary vector can be uniquely written as a linear combination of these three vectors. (They serve to define a set of 'oblique' axes). But **d** cannot have any component along **a**, because, as is easily seen, $\mathbf{b} \times \mathbf{c}$ is perpendicular to **b**, **c** and **d** but not to **a**. Therefore, in general, **d** must be expressible as

$$\mathbf{d} = \beta \mathbf{b} + \gamma \mathbf{c} \tag{7}$$

- where β and γ are *scalars*. Note that this argument is valid even in the case of oblique axes, i.e., **b** and **c** are *not* required to be perpendicular to **a**.

- **d** is of first order in each of the vectors **a**, **b** and **c**: that is, multiplying any one of them by a constant multiplies the answer by the same constant; further, **d** vanishes if any of these three vectors is zero. Therefore β must be proportional to $(\mathbf{a} \cdot \mathbf{c})$ and γ to $(\mathbf{a} \cdot \mathbf{b})$, as these are the only first-order scalars that can be formed from $(\mathbf{a}, \mathbf{c})$ and $(\mathbf{a}, \mathbf{b})$ respectively. Hence

$$\mathbf{d} = \lambda(\mathbf{a} \cdot \mathbf{c})\mathbf{b} + \mu(\mathbf{a} \cdot \mathbf{b})\mathbf{c} , \tag{8}$$

where λ and μ are absolute constants – dimensionless pure numbers – independent of **a**, **b** and **c**.

- But **d** changes sign if **b** and **c** are interchanged, because $\mathbf{c} \times \mathbf{b} = -\mathbf{b} \times \mathbf{c}$. Therefore

$$-\mathbf{d} = \lambda(\mathbf{a} \cdot \mathbf{b})\mathbf{c} + \mu(\mathbf{a} \cdot \mathbf{c})\mathbf{b} . \tag{9}$$

Comparison with equation (8) gives $\mu = -\lambda$, so that

$$\mathbf{d} = \lambda[(\mathbf{a} \cdot \mathbf{b})\mathbf{c} - (\mathbf{a} \cdot \mathbf{c})\mathbf{b}] . \qquad (10)$$

- Having nearly solved the problem, we may *now* determine λ by looking at an appropriate simple special case because equation (10) is valid for *all* **a, b, c**. Thus, setting $\mathbf{a} = \mathbf{i}, \mathbf{b} = \mathbf{i}, \mathbf{c} = \mathbf{j}$, we get $\mathbf{d} = -\mathbf{j}$ by direct evaluation of $\mathbf{a} \times (\mathbf{b} \times \mathbf{c})$, while the right-hand side of equation(10) gives $-\lambda\mathbf{j}$. Hence $\lambda=1$. We thus obtain the general formula quoted in equation (6).

The arguments used above can be repeated to tackle numerous other cases. Let us consider, for instance, the scalar product of $(\mathbf{a} \times \mathbf{b})$ and $(\mathbf{c} \times \mathbf{d})$, where **a, b, c, d** are four arbitrary vectors. We again observe that

- the expression is linear (of first order) in each of the vectors, and

- the presence of $(\mathbf{a} \times \mathbf{b})$ and $(\mathbf{c} \times \mathbf{d})$ does not allow any contribution proportional to $(\mathbf{a} \cdot \mathbf{b})$ and $(\mathbf{c} \cdot \mathbf{d})$. Hence the answer *must* be of the form

$$(\mathbf{a} \times \mathbf{b}) \cdot (\mathbf{c} \times \mathbf{d}) = \lambda(\mathbf{a} \cdot \mathbf{c})\,(\mathbf{b} \cdot \mathbf{d}) + \mu\,(\mathbf{a} \cdot \mathbf{d})\,(\mathbf{b} \cdot \mathbf{c}) \quad (11)$$

where λ and μ are pure numbers.

- As before, since the answer changes sign if **a** and **b** are interchanged, we get $\lambda = -\mu$.

- Finally, the overall constant factor is fixed by looking at a special case, e.g., $\mathbf{a} = \mathbf{c} = \mathbf{i}, \mathbf{b} = \mathbf{d} = \mathbf{j}$. This gives $\lambda = 1$. We thus obtain the familiar formula

$$(\mathbf{a} \times \mathbf{b}) \cdot (\mathbf{c} \times \mathbf{d}) = (\mathbf{a} \cdot \mathbf{c})\,(\mathbf{b} \cdot \mathbf{d}) - (\mathbf{a} \cdot \mathbf{d})\,(\mathbf{b} \cdot \mathbf{c}) . \qquad (12)$$

General considerations of linearity, symmetry (or antisymmetry), dimensionality, homogeneity, etc. practically determine the final answer in such problems.

The formulae (6) and (12) are, of course, well known, and several different proofs of their validity can be given. My aim has been to bring out the fact that *general considerations of*

linearity, symmetry (or antisymmetry), dimensionality, homogeneity, etc. practically determine the final answer in such problems. This is brought home even more convincingly in the example I came across sometime ago in an entrance test for admission to a research institute.

Evaluation of Some Integrals

We will first evaluate the integral

$$I_4 = \int (\mathbf{e}_r \cdot \mathbf{a})\,(\mathbf{e}_r \cdot \mathbf{b})\,(\mathbf{e}_r \cdot \mathbf{c})\,(\mathbf{e}_r \cdot \mathbf{d})\; d\,\Omega\,, \tag{13}$$

where the unit radial vector $\mathbf{e}_r$ varies over the surface of a sphere of unit radius centred at the origin. Here **a, b, c, d** are four arbitrary constant vectors, which is why I have used the notation I_4. (Such integrals occur in several contexts in physical calculations – for example, in the theory of collisions of particles). A brute force approach to the evaluation of I_4 is a formidable task, but there is a very 'physical' way of tackling the problem. We may try to simplify the task by choosing spherical polar coordinates with the polar axis along one of the given vectors, say **a**. But this does not help much, because there are *three* other vectors pointing in arbitrary directions. Instead, we note that I_4 (i) is a scalar, (ii) is of first order in *each* of the four vectors **a, b, c, d** and vanishes if any one of them is zero, and (iii) is *totally symmetric* under the interchange of any of these vectors among themselves. Therefore I_4 *must* be of the form

$$I_4 = \lambda\,[(\mathbf{a}\cdot\mathbf{b})\,(\mathbf{c}\cdot\mathbf{d}) + (\mathbf{a}\cdot\mathbf{c})\,(\mathbf{b}\cdot\mathbf{d}) + (\mathbf{a}\cdot\mathbf{d})\,(\mathbf{b}\cdot\mathbf{c})], \tag{14}$$

where λ is a pure number. The plus signs and the overall constant λ for each term follow from (iii) above. (To be precise – and this will be relevant further on – we have also used the fact that $(\mathbf{a}\cdot\mathbf{b})\,(\mathbf{c}\cdot\mathbf{d}) = (\mathbf{c}\cdot\mathbf{d})\,(\mathbf{a}\cdot\mathbf{b})$, as well as $\mathbf{a}\cdot\mathbf{b} = \mathbf{b}\cdot\mathbf{a}$.) Likewise, combinations such as $(\mathbf{a}\times\mathbf{b})\cdot(\mathbf{c}\times\mathbf{d})$ are not

allowed by this symmetry. (iv) The constant λ is now determined by going over to the special case $\mathbf{a} = \mathbf{b} = \mathbf{c} = \mathbf{d} = \mathbf{k}$ (the unit vector along the polar or z-axis). In that case, since $\mathbf{e}_r \cdot \boldsymbol{k} = \cos\theta$, I_4 reduces by direct evaluation to

$$I_4 = \int_{-1}^{1} d(\cos\theta) \int_0^{2\pi} d\psi \ \cos^4\theta = \frac{4\pi}{5} \qquad (15)$$

on the one hand, while equation (14) gives $I_4 = 3\lambda$ on the other. Hence $\lambda = 4\pi/15$, completing the evaluation of I_4.

Generalization is again tempting and possible! We see at once that all the odd numbered integrals I_1, I_3, I_5....must *vanish identically*, because there is no way that we can form a *scalar* from an *odd* number of vectors **a, b, c**,... that satisfies both (ii) and (iii) listed above. What about the corresponding general integral of *even* order,

$$I_{2n} = \int d\Omega \prod_{i=1}^{2n} (\mathbf{e}_r \cdot \mathbf{a}_i) \qquad (16)$$

involving the $2n$ arbitrary vectors $\mathbf{a}_1, \mathbf{a}_2, \ldots, \mathbf{a}_{2n}$? The arguments given earlier now yield

$$I_{2n} = \lambda \sum_{\{i_1\}} (\mathbf{a}_{i_1} \cdot \mathbf{a}_{i_2})(\mathbf{a}_{i_3} \cdot \mathbf{a}_{i_4}) \ldots (\mathbf{a}_{i_{2n-1}} \cdot \mathbf{a}_{i_{2n}}), \qquad (17)$$

where λ is a constant, yet to be determined, and $(i_1, i_2, \ldots i_{2n})$ is a permutation of (1, 2 ,..., 2n). An interesting little bit of combinatorics enters here. The summation in equation (17) is over all the possible permutations subject to the conditions that (i) $(\mathbf{a}_i \cdot \mathbf{a}_j)$ and $(\mathbf{a}_j \cdot \mathbf{a}_i)$ are not counted as two different combinations, and (ii) all the $n!$ permutations of each set of n scalar products $(\mathbf{a}_{i_1} \cdot \mathbf{a}_{i_2}) \ldots (\mathbf{a}_{i_{2n-1}} \cdot \mathbf{a}_{i_{2n}})$ are counted only once. The number of distinct terms in the summation in

(17) is therefore $(2n)!/(2^n n!)$. The special case of $\mathbf{a}_1 = ... = \mathbf{a}_{2n} = \mathbf{k}$ now gives

$$I_{2n} = 2\pi \int_{-1}^{1} d(\cos\theta)\, \cos^{2n}\theta = \frac{4\pi}{2n+1}, \qquad (18)$$

while the right-hand side of equation (17) reduces to $\lambda(2n)!/(2^n n!)$. The constant λ in equation (17) is therefore given by

$$\lambda = 2^{n+2}\pi \frac{n!}{(2n+1)!}. \qquad (19)$$

This completes the evaluation of the general integral I_{2n}.

A *further* generalization of these results that suggests itself (and which may indeed occur in actual calculations) is the evaluation of such integrals in an arbitrary number d of *dimensions*. In other words, what is

$$I_{n,d} = \int d\Omega\, (\mathbf{e}_r \cdot \mathbf{a}_1) \ldots (\mathbf{e}_r \cdot \mathbf{a}_n), \qquad (20)$$

where $\mathbf{e}_r$ varies over the surface of a unit sphere in d–dimensional (Euclidean) space? I leave the further exploration of this question to the reader.

Concluding remarks

In the next part of the series we will see how, taking off from the simple vector identity in equation (6), we can understand concepts such as reciprocal bases, dual spaces, and bra and ket vectors. These concepts are extremely useful in many branches of physics including, among others, quantum mechanics and solid state physics.

I am indebted to S Seshadri for his invaluable assistance in the preparation of this series of articles.

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Life : Complexity and Diversity

4. Scales of Diversity

Madhav Gadgil

Madhav Gadgil is with the Centre for Ecological Sciences, Indian Institute of Science and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. His fascination for the diversity of life has prompted him to study a whole range of life forms from paper wasps to anchovies, mynas to elephants, goldenrods to bamboos.

With rare exceptions, each sexually reproduced individual is endowed with a distinctive genetic constitution. Nevertheless living organisms share many genes, the greatest level of sharing characterizing those belonging to the same species. The total number of such species is unknown, but probably exceeds ten million, the vast majority of them being small invertebrate animals.

Diversity within a Species

The diversity of life manifests itself at a variety of levels. At the lowest spatial scale, it may be viewed as diversity of the hereditary material, the molecules of nucleic acid which carry the instructions for conducting much of the business of life. Living organisms reproduce in two different ways: with or without intervention of sexual union. Most higher organisms reproduce sexually, through coming together of egg and sperm cells. The gametes carry only half the hereditary material of the parent after shuffling of parental combinations of genes through genetic recombination. Thus each of the sex cells is different from the other. As a result every individual formed through their union will be unique. Billions of individuals produced through sexual reproduction on earth are in some way different in their hereditary constitution from each other. The extent of variation is a little circumscribed in species that are not products of sexual reproduction. For instance, when a yeast cell splits into two, both cells may carry identical hereditary material; when a curry leaf tree or an Indian cork tree produces new plants from root sprouts, the daughter plants may be identical in their genetic complement to the mother plant. In very special cases,

such as identical twins in our own species, even sexually produced individuals may carry identical hereditary material. But these are rare exceptions.

Generally, members of a species are interfertile and may breed with each other under natural conditions

Almost every sexually produced individual is different from every other in some detail of its hereditary material. But two such individuals may also be similar in many ways. Indeed a mother and a daughter at a minimum share half their hereditary material. If the husband and wife shared some traits, as they often would, then the mother and daughter would share much more than half of the hereditary material. Sets of individuals would share more genetic material with other members of the set such as for instance, all human beings, or all bonnet macaques, or all domesticated donkeys, or all banyan trees. Having much in common, such individuals are potentially capable of reproducing with members of the opposite sex within the set. These constitute what biologists call species. Generally, members of a species are interfertile and may breed with each other under natural conditions. So all humans constitute one species, all tigers another, all lions a third. Although lions and tigers may interbreed in zoos, they never do so in nature, and therefore deserve to be considered as separate species. On the other hand, white Europeans, black Africans, mongoloid Orientals, Australian aborigines, are all perfectly interfertile and are clearly members of the same human species (Figure 1). Diversity of life is therefore best viewed in two major contexts: diversity of hereditary material amongst members of the same species, and the diversity of species within a biological community, or in any specific region such as the Indian subcontinent.

Diversity of life is therefore best viewed in two major contexts: diversity of hereditary material amongst members of the same species, and the diversity of species within a biological community.

The recent knowledge of the primary sequence of hereditary material has brought in a great deal of information on the extent of variation amongst members of the same species. The hereditary material of any individual is made up of several thousand to several hundred thousand units or genes. There

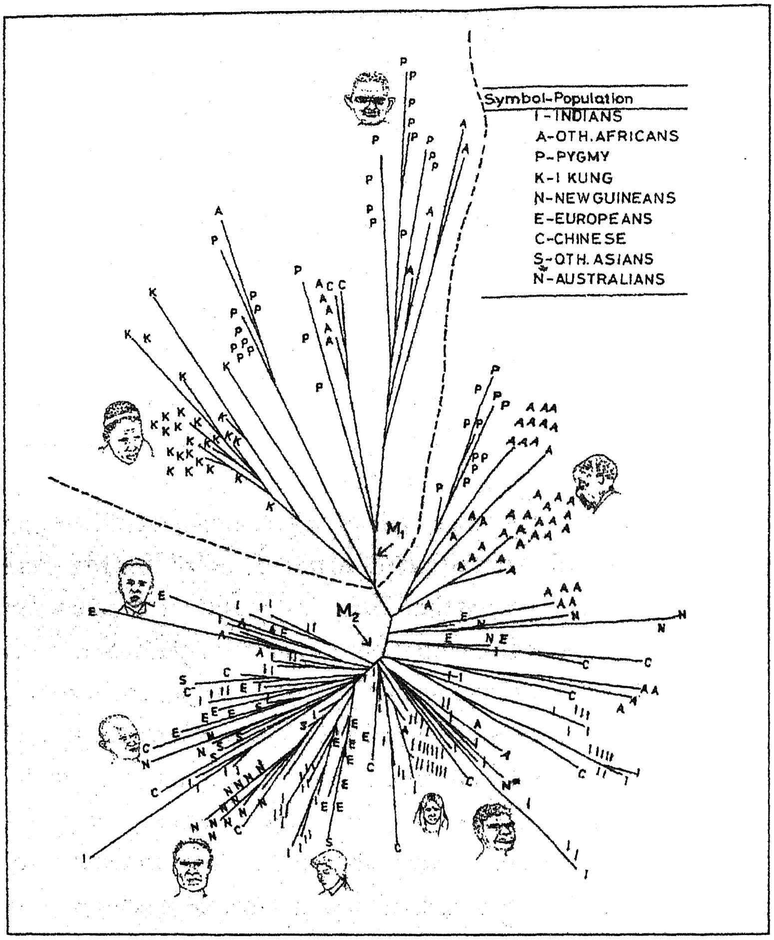

Figure 1 A tree depicting genetic relationships amongst modern humans. This tree is based on 745 nucleotide base sequences of 293 individuals from a highly variable region of mitochondrial DNA. While Africans and non-Africans tend to cluster separately, Europeans, Asians and Australian aborigines are intermingled (based on J L Mountain, J M Hebert, S Bhattacharyya, P A Underhill, C Ottolenghi, M Gadgil, and Cavalli-Sforza. Demographic history of India and mtDNA – sequence diversity Am. J. Hum. Genet., 56:979-992. 1995).

is little variation for 60% to 80% of these genes; they are believed to be identical in all members of a given species. Several forms occur at the remaining 20% to 40% of the genes. Every individual in a sexually reproducing species carries two sets of genes, one derived from the mother, the other from the father. Between 5% and 14% of these two sets of genes are in more than one form; for instance the mother having contributed a gene for brown and the father for black eyes. This diversity within species is of great significance as the raw material for evolutionary change. For instance, mosquitoes in many parts of India are no longer killed by DDT. This is because the mosquito species contained some individuals with genes that permitted the bearers to withstand exposure to DDT.

Sexually reproducing organisms are polymorphic at 20% to 40% of genetic loci.

Before DDT came into vogue there were very few individuals carrying such genes. But once DDT began to be sprayed on a large scale such individuals were at a great advantage. They survived while mosquitoes bearing genes that rendered them susceptible to DDT were killed. So gradually the proportion of mosquitoes with genes conferring DDT resistance has increased till most Indian mosquitoes today are DDT resistant. The tremendous diversification of life from a single origin three and a half billion years ago till today is ultimately based on such evolutionary change for which genetic variation within species has provided the basic raw material.

The tremendous diversification of life from a single origin three and a half billion years ago till today is ultimately based on such evolutionary change for which genetic variation within species has provided the basic raw material

So much for variation within a species. Higher levels of differences in the hereditary material mark one species from another. Where they are closely related, as in the case of humans and chimpanzees, much of the hereditary material is held in common. Thus humans and chimps have about 98.4% of the same genes, although the exact form of the genes would differ for a much larger proportion. We share about 97.7% of the genes with gorillas, 96.4% with Orangutans, and 93% with other old world monkeys (*Figure 2*). But even very different organisms such as green plants and mammals have a proportion of widely

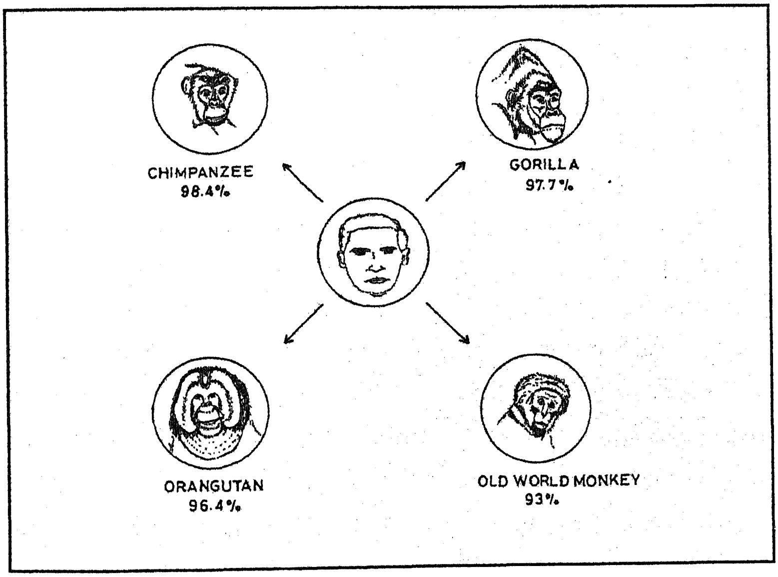

***Figure 2** While there may be considerable variation amongst allelic forms of given genes even amongst members of a given species, related species have much of their genetic material in common. This figure depicts this relationship amongst the human species, other apes and old world monkeys.*

The gene coding for the production of a protein called Histone H4 differs in only 2 out of 100 amino acids in organisms as different as the pea plant and cattle.

shared genes -- for instance the gene coding for the production of a protein called Histone H4 involved in binding nucleic acids. This protein differs in only 2 out of 100 amino acids in organisms as different as the pea plant and cattle.

Diversity Across Species

The most striking aspect of diversity around us is that of different kinds of species of living organisms. The viruses that we cannot see, but that we broadcast with every sneeze; the bacteria that we cannot see, but drink with every glass of buttermilk, the mold that grows on rotting fruit, the mushrooms that grow on rotting logs of wood, the banyan trees that line our avenues, the fig wasps that live inside the fruit of banyan trees, the crimson breasted barbets and the koels that feed on these fruit. How many such different species of living organisms are there any way? What we know for sure is that about a million and a half have been described in scientific literature to this date. A quarter of a million of these are plants, over a million insects and spiders. Only 4000 different species of bacteria and 5000 of viruses have been described. There are 45000 species of vertebrates described – fish, frogs, snakes, turtles, birds, mammals all put together. There are almost an equal number, 40000 species of crabs, shrimps and related crustacean animals described.

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But every day new species are being discovered and described. Many of these are small insects and mites a few millimeters in size living in the canopy of tropical forests. It is speculated that there may be as many as ten to fifty million species of such animals still unknown to science. Most of the vertebrates have probably already been described, and perhaps only another 5000 or so remain to be added to the known list of 45000. So one can only speculate on the total number of species of living organisms on the surface of the earth today. Very likely it is around 15 million, ten times the number of species described. But it could be as many as 100 million.

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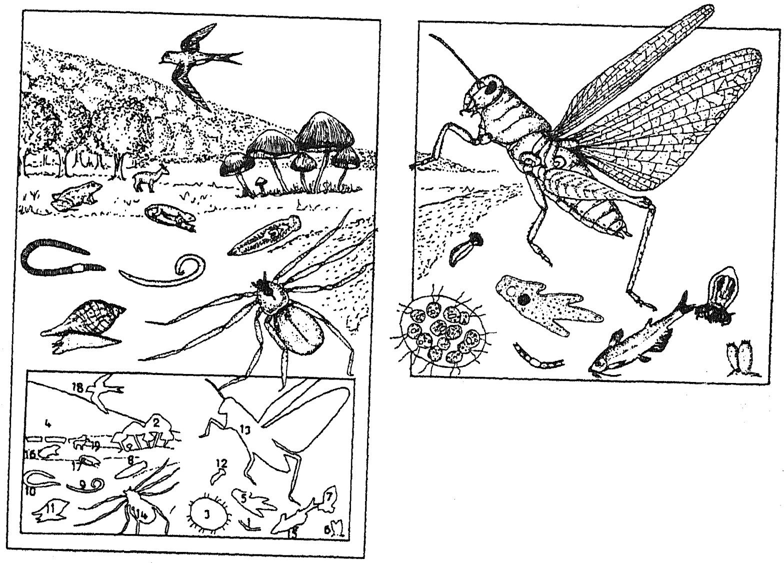


A Species Scape

There is a tremendous variation in the number of species belonging to different groups of organisms; this variation is indicated by the relative sizes of different organisms. Thus there are many more species of insects and crabs and their relatives. Consequently these loom much larger in the species scape than do fishes or frogs. The code and number of species described so far from the various groups are given below. This list omits viruses and some minor groups of invertebrates.

1 Monera (bacteria, cyanobacteria), 4800
2 Fungi, 69,000
3 Algae, 26,900
4 Higher plants, 248,400
5 Protozoa, 30,800
6 Porifera (sponges), 5000
7 Cnidaria and Ctenophora (corals, jellyfish, comb jellies and relatives), 9000
8 Platyhelminthes (flatworms), 12,200
9 Nematoda (roundworms), 12,000
10 Annelida (earthworms and relatives), 12,000
11 Mollusca (mollusks), 50,000
12 Echinodermata (starfish and relatives) 6,100
13 Insecta, 751,000
14 Non-insectan arthropods (crustaceans, spiders etc) 123,400
15 Fishes and lower chordates, 18,800
16 Amphibians, 4,200
17 Reptiles, 6,300
18 Birds, 9,000
19 Mammals, 4000

Jeans and Means

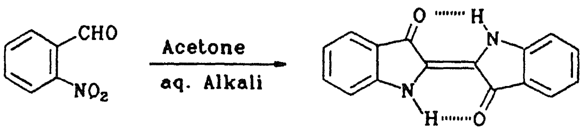
3. The Story of Indigo

Subramania Ranganathan

The mechanism of formation of indigo from 2-nitrobenzaldehyde and acetone is discussed in this article. Some new methods of making indigo are also described.

After nearly a three-decade long innings as an inspiring teacher and researcher at IIT Kanpur, S Ranganathan is now at RRL, Thiruvananthapuram. He and his chemist wife, Darshan, plan to set up (without government assistance) 'Vidyanatha Education Centre', to promote education, art and culture.

The organic chemist is a creator. It is this fact that contributed a great deal to the early development of organic chemistry. The early realisation that many useful compounds could be made more economically in the laboratory than from natural sources and the pursuit of such prospects in the dye industry were responsible for the development of organic chemical industries. Discoveries became the logical outcome of prolific and intuitive experimentation as exemplified by Perkin's synthesis of mauve in 1856 and Baeyer's synthesis of indigo in 1878. The remarkably simple synthesis of indigo (1) from 2-nitrobenzaldehyde and acetone in the presence of aqueous alkali (eq. 1) must have come as a most pleasant surprise.



2 1 .... (1)

Today we can explain the reaction; yet, by any standards it is still fascinating. In this article, we will try to analyse the steps involved in the synthesis of indigo. The mechanistic approach will be further simplified through a short discussion on oxidation numbers of organic compounds.

Even to this day, the mechanism of the alkali–mediated chemical transformation shown in equation 1 is some food for

Indigo [from Greek *indicon* , Indian substance] is perhaps the oldest dye known and has a history dating back to 5000 years. Indigo has attracted merchant ships to India since ancient times. No other naturally occurring material could give cotton the kind of lovely blue as indigo could. The trade suffered badly towards the later part of the last century, since the industrial preparation of indigo virtually wiped out indigo cultivation. Interestingly, we may end up going back to the natural sources for getting indigo, albeit in a different way, through genetically engineered organisms.

The increase in the demand for indigo is a direct result of the fascination for blue jeans, that has neither gender nor age bias. The origin of jeans as an apparel makes an interesting story. The city of Genoa in Italy specialized in making sail ships. The sails were, naturally, made of rough and tough cotton. An entrepreneur found that old, dirty, torn sails could be dyed with indigo and sold as dress material. Thus jeans were born. People liked jeans, for they were comfortable. Nowadays jeans come in different hues, like stone washed, bleached and machine gunned! It seems that jeans are here to stay. With increasing demand the price of jeans is going up and along with it the price of indigo. This and environmental factors will in the very near future make the preparation of indigo by natural means a preferred option.

Johann Friedrich Adolf von Baeyer (1835-1917) was awarded the chemistry Nobel prize in 1905 in recognition of his services to the development of organic chemistry and chemical industry through his work on organic dyes and hydroaromatic combinations. Baeyer's name is synonymous with indigo and his impact on science was profound. His life is an inspiration to scientists. His first achievement was the preparation of barbituric acid, commonly known as sleeping pills. By 1880 he became well known for his work on indigo and other synthetic organic compounds, which were patented and marketed successfully. With his student, William Perkin, he formulated the Baeyer strain theory which indicated why rings of five and six carbon atoms are most common. Among the other notable students were Thiele, Schlenk, Wieland, Meyer, Emil Fischer and Otto Fischer.

Baeyer studied chemistry at Heidelberg University with Bunsen, whose emphasis on the importance of physics in chemical training and research is well known. Additionally, he had the good fortune of having Kekule as his teacher. One of the greatest characteristics of Baeyer's research was his ability to use simple equipment. His dictum was that good research can be done in simple, home-made fashion (an aspect our chemists could take note of!). One day a student brought a mechanical stirrer to the laboratory. Baeyer spotted the gadget and was immediately apprehensive and suspicious of its merits. He sought the opinion of Mrs Baeyer and her first remark on seeing it was, "what a lovely way of making mayonnaise!" [whipped egg and olive oil, essentially]. Baeyer, it appeared, was speechless; the stirrer stayed and proliferated!

Analysis of the Oxidation Number of Organic Compounds

1. For a bond that connects the same atoms [regardless of the nature of ligands attached to it] the oxidation number count is zero. For example, the *contribution* from each carbon below is '0':
   Examples:
   $H_3C\text{-}CH_3$, $H_2C = CH_2$, $H_3C\text{-}CH_2OH$, $H_5C\text{-}CH_2\text{-}CH_3$
2. The oxidation number contribution of bond A-B will be related to the electronegativities or dipole moments. That is, the positive end contributes +1 and the negative end -1.
   Examples:
   $\underset{-3\ -3}{H_3C\text{-}CH_3}$, $\underset{-3\ -1}{H_3C\text{-}CH_2OH}$, $\underset{-3\ +1}{H_3C\text{-}CH{=}O}$, $\underset{-3\ +3}{H_3C\text{-}COOH}$

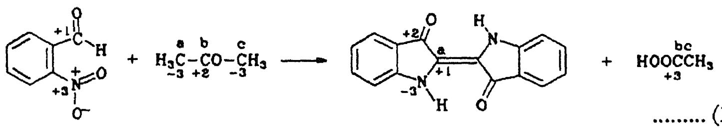
   This example shows how the progressive two-electron-oxidation of ethane to acetic acid, changes the oxidation number of the oxidised carbon by two units at a time.
3. Over and above the computed number, for every positive charge +1 should be added and for every negative charge –1 should be added.
   Examples: $\underset{-4}{H_3C^-}$, $\underset{-3}{H_3C\cdot}$, $\underset{-2}{H_3C^+}$, $\underset{-3}{H_3N}$, $\underset{-3}{H_4N^+}$

An analysis similar to the one above would show that for the progressive two electron reduction of a nitro compound to an amine, the oxidation number of the nitrogen atom decreases by two units at a time.

thought! We will try to understand the details of this transformation in two stages, through the analysis of the changes in oxidation numbers.

The concept of oxidation numbers has greatly simplified the analysis of transformations in the inorganic area, such as balancing equations. A similar concept, although too simplistic, is equally useful in organic chemistry. The rules for determining the oxidation numbers of atoms in organic molecules are summarised in the box.

From this perspective, eq. 1 can be rewritten with the oxidation numbers of the important atoms as follows:

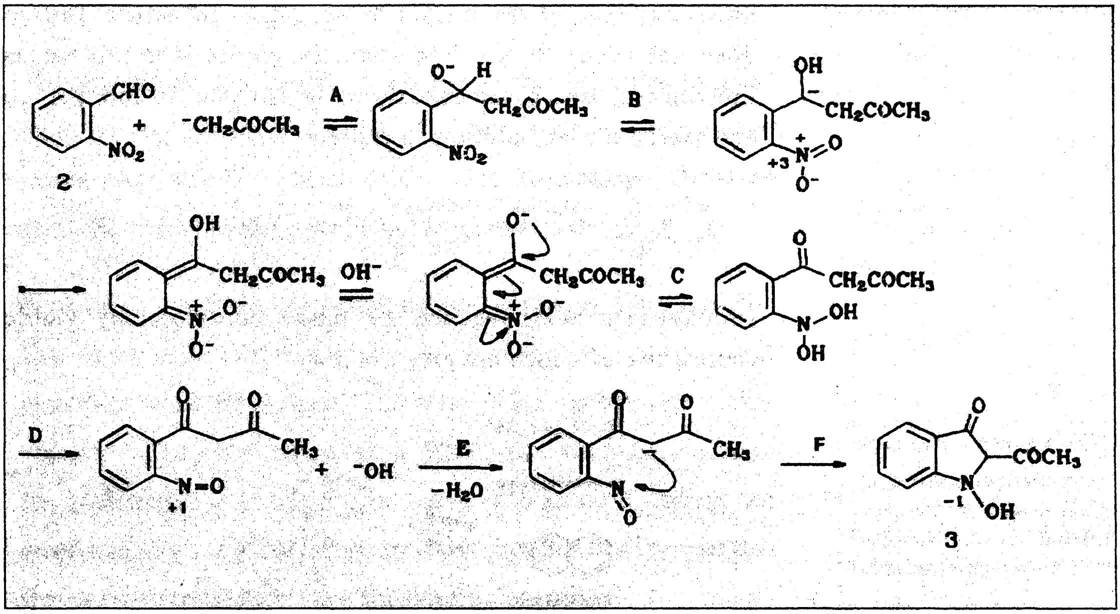


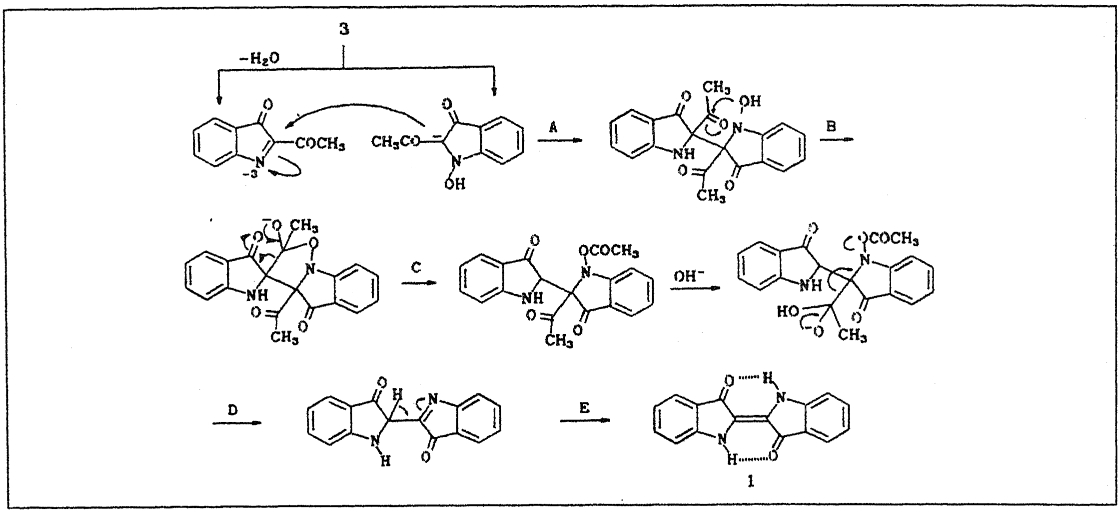
.... (2)

There is a remarkable change in the oxidation number of the nitrogen atom during the reaction. Of the six electrons needed for the $NO_2 \rightarrow NHR$ (+3 to –3) change, five have come from acetone and one from the aldehyde group. Here the transfer of electrons has been 'done' in a clever manner through a series of transformations shown in *Schemes 1* and *2*.

The presence of alkali is important in deprotonating acidic hydrogens to produce nucleophilic species, which undergo reactions characteristic of them. The acid-base equilibria also promote hydrogen transfers. With these general ideas in mind, we can divide the overall transformation of **2** to **1** into two segments. The first cascade of reactions is triggered by the addition of $CH_3COCH_2^-$ (formed by an acid-base reaction of acetone with OH^-) to the aldehyde group of **2**. This ultimately leads to the formation of compound **3** via nucleophilic addition, hydrogen transfer and dehydration steps. The sequence is shown in *Scheme 1*. The changes in the oxidation number of nitrogen at crucial stages are also indicated.

Scheme 1 A: nucleophilic addition; B: hydrogen shift; C: aromatization and protonation; D: dehydration; E: deprotonation and F: intramolecular nucleophilic addition.

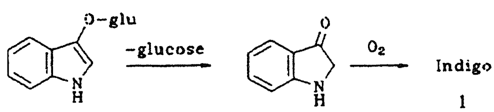




Scheme 2 A & B: nucleophilic addition; C: retro-aldol reaction; D: fragmentation and E: tautomerisation.

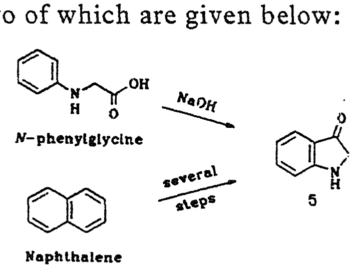
The second sequence of reactions begins with the coupling of two species, both generated from 3. Through a series of nucleophilic addition, fragmentation and tautomerisation steps (*Scheme 2*) indigo is 'magically' formed!

The structure of indigo as **1** was established only in 1883, five years after Baeyer's synthesis. Later, routes to indigo were discovered rapidly and many of these were commercially exploited. These endeavours were facilitated by the understanding of the formation of indigo in nature. Indigo does not occur in the free form. In plants it is present as indican (4), which can readily be hydrolysed to indoxyl (5) and which can be oxidised to indigo.



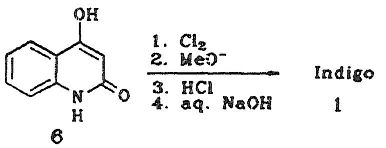
4 5 .... (3)

Indoxyl has been reached by many commercially viable routes, two of which are given below:



5 .... (4)

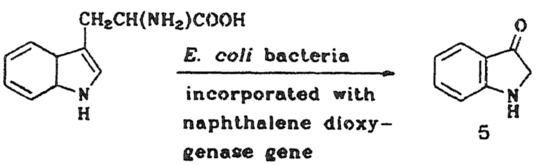
The quantitative transformation of 4-hydroxycarbostyril (6) to indigo (eq. 5) is a process of recent origin. It demonstrates that the quest for indigo by exotic pathways is by no means over.



.... (5)

It would be challenging to work out how the $6 \rightarrow 1$ change takes place.

Although it may not strike us as elegant, many compounds currently prepared by organic synthesis can be made by genetically manipulated organisms. This trend will not only cut down costs but would also obviate environmental hazards, invariably associated with synthetic procedures. The case of indigo provides an excellent example. This route may prove to be the preferred procedure for large scale preparation of indigo.



.... (6)

Modern chemistry is also emerging from molecules derived from the modification of 1. In 1995 indigo was converted into sheet materials by thermolysis. The thioindigo [NH=S] skeleton has been used as a photochemical switch.

A problem, once solved, usually loses its charm. Occasionally, the same problem resurfaces in a different context and generates renewed interest. The story of indigo belongs to this category. The need for making indigo has changed. So have the parameters that have to be taken into account during the synthesis. But, the challenge to one's creative ability remains the primary motivation for the organic chemist.

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Geometry VI

6. Space – the Final Frontier

Kapil H Paranjape

After spending about a decade at the School of Mathematics TIFR, Mumbai, Kapil H Paranjape is currently with Indian Statistical Institute, Bangalore.

In this concluding article of the series the author gives a brief overview of some modern aspects of geometry—Topology and Algebraic Geometry. The subject is now so vast that it is best to learn about it from the excellent books available—some of which are suggested at the end.

Holes in the Whole

The studies of Gauss and Riemann described in earlier articles can be classified as *local* geometry. Some geometrical attributes such as 'holes' or equivalently the notion of an object 'closing upon itself' are *global*. The first mathematical measure of this kind was described by Euler.

A (convex) *polyhedron* is a finite body bounded by planes so that any point lying between two points of the polyhedron also lies in the polyhedron. The boundary of a polyhedron then consists of a number F of (plane) polygonal faces which meet in edges (linear segments) that are E in number. The edges terminate in vertices (points) that are V in number. The numbers V, E, F differ according to the polyhedron we choose, but as Euler proved we always have the identity

$$V - E + F = 2$$

In order to understand the nature of this statement let us look at the similar statement for polygons (which are the two dimensional analogues of polyhedra). The boundary of a polygon has say E edges and V vertices where we have $V - E = 0$ (Exercise). Euler's proof is entirely analogous and quite elementary.

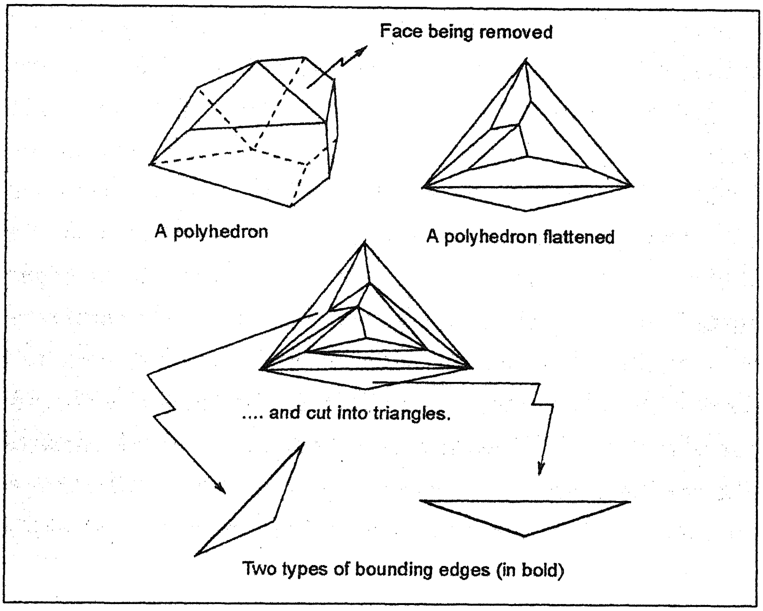

Figure 1 Euler's proof

We remove one face of the boundary of the polyhedron after which it can be 'flattened' onto the plane. We then cut each polygon into triangles as shown in *Figure 1*. This doesn't change the quantity $V - E + F$ (Exercise). Each bounding edge now occurs in one of the two configurations shown in *Figure 1*. Removing one edge in the first case and the two bounding edges and the included vertex in the other case makes exactly one face disappear. Thus this operation does not change $V - E + F$. By successively whittling down the figure in this manner we obtain a triangle. We then have $3 - 3 + 1 +$ (the one face removed originally)$=2$. Now we may take various common objects and flatten the round edges (in one's mind) and obtain a (finite) solid object bounded by polygonal faces. The only property of a polyhedron that is missing would be that of *convexity*. We could then calculate the *Euler characteristic* $V - E + F$ for the boundary of such an object and ask what we would obtain. The answer turns out to be an even number of the form $2(1- g)$ where g (called the *genus*) is the number of 'holes' that the body[1] has (Exercise: Convince yourself of this regarding various objects around you).

[1]For example, the doughnut has one hole and the sphere none. One can also consider more complicated handle-bodies i.e. a sphere with handles attached. A doughnut can be thought of as a sphere with one handle attached – why?

It is important to note that this number does not depend on exactly how the flattening is done. Indeed one could perform the reverse operation and 'pop' out the polyhedron to obtain 'curved' edges and faces – this would not change the formulae. Recall the formula of Gauss that the integral of the curvature on a triangle whose sides are geodesics is the sum of the angles of the triangle reduced by π. Assuming that the edges of the 'curved' polyhedron are geodesics (this can be achieved by a suitable deformation) we can then deduce the 'global' formula of Gauss and Bonnet. The sum of the angles around any vertex is 2π. Thus, if S is a (compact oriented) surface, like the boundary of a 'handle-body' mentioned earlier, then the integral of the curvature over the surface is

$$2\pi \times (\text{the number of vertices}) - \pi \times (\text{the number of triangles}).$$

Now each triangle has three edges and one face and each edge lies on two triangles; thus we have $2E=3F$ so that $V-E+F=V-F/2$ in this situation. Putting it all together we obtain

$$\int_S (\text{curvature}) = 2\pi \times (\text{Euler characteristic})$$

The Euler characteristic is only the first in a series of numbers and invariants that are defined for higher dimensional objects. The subject that studies such invariants is called *algebraic topology* and grew out of the works of Poincaré, Betti, Emmy Noether, Alexandroff and Lefschetz.

The Simplicity of Complex Objects

In addition to the paper of Riemann discussed in the earlier article, one other paper by him contributed tremendously to geometry. This was his paper on the geometric theory of functions of one complex variable. This paper gave rise to many beautiful geometrical ideas, some of which are briefly sketched below. This concluding section is not as

self–contained as earlier parts of this series, but one hopes it will whet the appetite of some of our readers so that they consult the books listed at the end.

To understand what function theory has to do with geometry, let us wind the clock back a bit. Gauss (and Argand) had shown that the collection of all numbers of the form $a+\sqrt{-1}\,.\,b$ can be thought of as a plane (nowadays called the complex plane or sometimes even the complex line!). It was known (to Cauchy and others) that the notion of differentiability with respect to complex numbers is a very severe restriction[2] on functions. In particular, the Taylor expansion of such a function f

[2] Contrary to a common misconception among beginning calculus students, the Taylor series does *not* converge for 'most' functions.

$$f(z) = f(z_0)+f'(z_0)(z-z_0)+\frac{f''(z_0)}{2!}(z-z_0)^2+\cdots$$

converges absolutely for all z in the complex plane that lies within a certain radius of z_0. (Exercise: To see why this is a restriction, the reader is encouraged to compute the derivatives of all orders of the function exp $+(-1/x^2)$ at x=0). These properties imply (as Riemann pointed out), that any differentiable function of one complex variable is naturally defined on a 'generalised' planar region that consists of a number of 'sheets' lying over the complex plane glued together in a manner depending on the function being considered; this is today called the *Riemann surface* of the function. One example is the function $w=\sqrt{z}$; the Riemann surface consists of a complex plane with w as the coordinate variable. This lies over the z-plane in two sheets by sending the point with coordinate w to the point with coordinate $z = w^2$. A more interesting example is the function $w = \sqrt{z^3-z}$. It is clear that but for the points z=0, ± 1 there are exactly two values of w, so that we again have a Riemann surface with two sheets. However, in this case there is *no global coordinate* on the Riemann surface[3].

[3] The uniformisation theorem formulated by Riemann can be thought of as a way of salvaging this situation.

Thus a geometric object can be associated with every differentiable function of one complex variable. Obviously, the study of this geometric object will provide information about the function. One important case is when the number of sheets is finite. Riemann showed that this is precisely the case of an algebraic function $w = f(z)$; i.e. one which satisfies an equation of the type

$$a_n(z)w^n + a_{n-1}(z)w^{n-1} + \cdots + a_0(z) = 0$$

where $a_k(z)$ are polynomial functions of z. Riemann showed that the surface can be identified with the boundary of a handle-body in this case; for example, the second Riemann surface considered above has genus 1 (*Figure 2*).

The equation above can be thought of as defining a curve in the plane (z, w) except that these variables are allowed to take complex values; for this reason we also refer to it as a complex algebraic curve. The relation between the geometry of a complex algebraic curve and its function theory was extensively studied by Brill and Max Noether[4]. The latter also extended this to the theory of complex algebraic surfaces; the famous Italian school of geometry grew out of his work. Following this, the purely algebraic approach led Chevalley, Weil and Zariski to formulate the theory of algebraic varieties. Algebraic geometry grew out of these seminal works.

[4] Emmy Noether was the daughter of Max Noether and developed much of the algebraic framework needed to give concrete and rigorous support to his results.

Summary

Differential geometry (which was introduced in the earlier article), topology and algebraic geometry form three major streams in the study of geometry today. Euclidean geometry survives as the study of linear spaces which is encompassed by linear algebra and lies at the basis of all geometrical research. The reader is advised to study some linear algebra from a good book on algebra such as the one by M Artin.

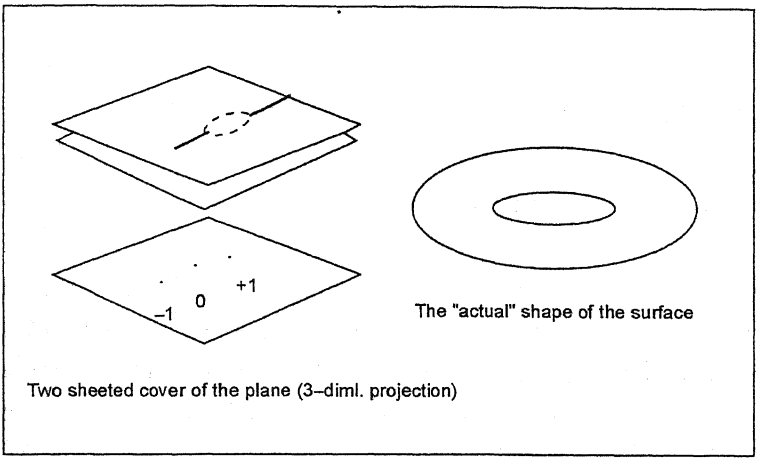

Figure 2 The Riemann surface of $w^2 = z^3 - z$

There are more things left unsaid in this short series than those that have been said. Each geometer without doubt would have her/his own list of beautiful items that have been ignored by the author. It can only be hoped that the reader has acquired an eagerness to explore these unexplored ideas. The author hopes he has demonstrated that this is a far more fruitful exercise than spending time squaring the circle or trisecting the angle.

I would like to thank V Pati for patiently hearing out my ideas and especially for pointing out flaws. Most importantly I am very grateful to A Sitaram for encouraging me to write this series and bearing with my occasionally boring re-working of old themes. I learnt most of the geometry I know from my teacher S Ramanan who turns sixty this year; I dedicate this series to him on this occasion and hope it meets his exacting standards.

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Questioning a Dogma

Do Bacteria Know When and How to Mutate ?

Milind G Watve and Neelima M Deshpande

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For over half a century, all mutations were believed to be 'random', i.e. independent of their effects on the organism in a given environment. This belief was strengthened by experiments by Luria and Delbruck and Lederberg and Lederberg in the middle of the century. Recently, however, many experiments have provided evidence to the contrary. A hot debate therefore ensues at the central stage of evolutionary genetics.

The central dogma of evolutionary biology, widely accepted today, is that of random mutations and natural selection. The genetic information in all living organisms, which is in the form of DNA (sometimes RNA), is conserved and passed on from generation to generation by means of faithful replication of DNA. Errors in replication, however, do take place. These are called mutations. Sometimes mutations are silent, i.e. they do not affect the functioning of the organism in any detectable way. But at other times they affect the characteristics of the organism to a lesser or greater extent. Mutations thus cause variations in the population and natural selection chooses the best of the lot. While the existence and importance of natural selection is seldom questioned, the 'randomness' of mutations has been a case for heated arguments ever since the birth of the concept of 'random mutations'.

A *random* or *spontaneous* mutation means mutation without any purpose or foresight. The organism cannot judge the environment and decide which mutation is likely to be useful under the given circumstances and somehow create it.

Undergraduate students and teachers often conceive of spontaneous mutations as the ones that take place in the absence of a mutagenic agent. This definition is problematic and should be abandoned. If mutations are only errors of replication, they have to be random according to this definition. People have however always found it difficult to believe that the basis of the process that has given rise to systems as complex as the human being is nothing but random errors. Are we humans the result of random errors? Doesn't it sound ridiculous? Neo-Darwinists such as Richard Dawkins have strongly and effectively defended the random mutation - natural selection dogma and argued that such a seemingly simple process can indeed give rise to extremely complex organizations.

Undergraduate students and teachers often conceive of spontaneous mutations as the ones that take place in the absence of a mutagenic agent. This definition is problematic and should be abandoned. People have always found it difficult to believe that the basis of the process that has given rise to systems as complex as the human being is nothing but random errors.

An alternative school, popularly called 'Lamarckian' (after Jean Baptiste de Lamarck 1744-1829) believed that organisms adapt to their environment by changing themselves and these changes are inherited. One can definitely smell a purpose or foresight in the Lamarckian argument. Today there are few takers for this notion. But Lamarckian thought has always played the role of a potential challenger to Darwinian thought. The experiments which turned the opinion strongly in favour of Darwinism were those by Luria and Delbruck, and Lederberg and Lederberg.

Lamarckian thought has always played the role of a potential challenger to Darwinian thought.

The Spontaneous Mutation Strongholds

Luria and Delbruck took cultures of a bacterial species, *Escherichia coli*, which were sensitive to the bacteriophage T1. If one plates a bacterial culture onto a nutrient gel along with a bacteriophage, the phage will kill the sensitive bacteria. Only the resistant ones can grow and form visible colonies. This is a tricky situation. There is no way to know whether a cell is resistant to the given phage unless it is plated in presence of the phage. Therefore there is no simple way to

know whether a mutation conferring resistance has occurred before or after exposure to the phage. Luria and Delbruck made complex statistical arguments to support the hypothesis that mutations had taken place before exposure to the phage. They divided one culture of *Escherichia coli* (culture A) into many small test tubes and incubated them overnight to allow the cells to multiply for several generations. Another culture (culture B) that was not divided into aliquots was simultaneously incubated. After incubation the contents of each tube were plated out along with the phage. Culture B was also plated a number of times with the phage. The number of colonies on the plates containing the phage, i.e. the number of phage–resistant mutants was counted after incubation.

The results obtained by Luria and Delbruck supported the spontaneous mutation hypothesis.

The experimenters reasoned that if resistance developed after exposure to the phage, then the number of resistant mutants in each plate should remain more or less the same. On the other hand if mutations occurred before plating out, they may have occurred at any point in time, that is randomly during incubation. Some of the plates may show very few or no mutants. Some of the others, (aptly called 'jackpots') where mutations might have occurred early would have a large number of mutants, as mutants grow exponentially (*Box 1*). Thus after plating, one will observe large variations or 'fluctuations' in the number of colonies in culture A. The undivided set B works as a control in which smaller variations in the number of mutant colonies in different plates are expected since the mutants can be distributed randomly. In statistical jargon, the number of mutants in set B will show Poisson distribution, whereas those in set A will show a highly aggregated frequency distribution.

The results obtained by Luria and Delbruck supported the spontaneous mutation hypothesis since the distribution in the case of culture A was highly aggregated (*Box 1*). The kind of distribution generated is often referred to as Luria Delbruck

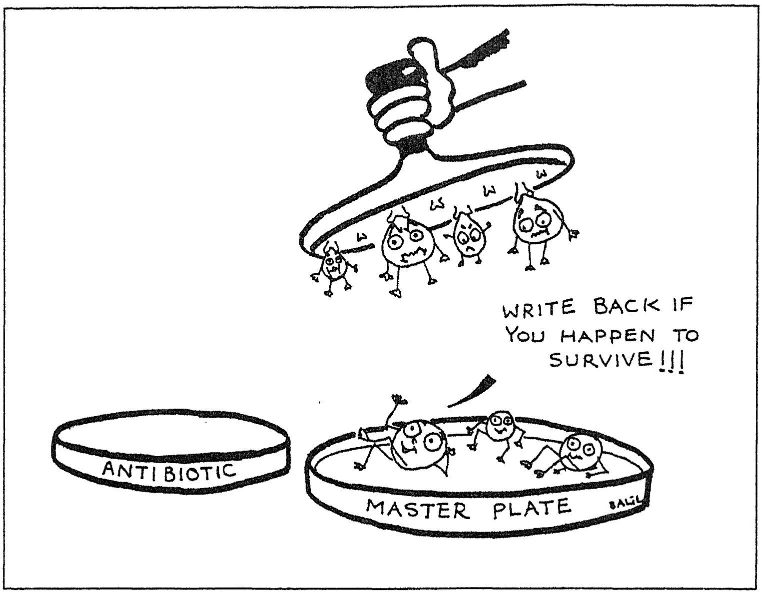
Here is the original experimental data obtained by Luria and Delbruck, which was published in '*Genetics*' in 1943.

Culture A (small individual cultures)	Culture B (samples from large culture)
1	14
0	15
3	13
0	21
0	15
5	14
0	26
5	16
0	20
6	13
107	mean = 16.7
0	variance = 15
0	
0	
1	
16	
17	
18	
19	
20	
0	
0	
64	
0	
35	
mean = 11.4	
variance = 694	

In culture B, as explained in the text, the distribution follows Poisson, an important property of which is that the ratio of variance to mean is approximately equal to 1. In the Luria-Delbruck distribution seen in culture A, on the other hand, variance exceeds the mean several fold. The two jackpots are clearly seen as 107 and 64 respectively.

distribution. Even after half a century of its formulation, it is routinely used for the calculation of mutation rates in bacteria.

These arguments were rather too mathematical for most of the biologists and the most common reactions were either uncritical acceptance or uncritical rejection. Biologists were more convinced by the ingenious 'replica plating' technique developed by Lederberg and Lederberg about ten years later



which made it possible to isolate mutants in pure culture without exposing them or their direct ancestors to a selective agent. Replica plating consists of simultaneously transferring a few cells each from all the colonies on a plate to another plate by means of a velveteen covered stamp pad. This replication of the master plate precisely preserves the geometric location of each colony. And that is the key point. If the master plate is non-selective and the replica plate contains the selective agent, say an antibiotic, only the antibiotic-resistant mutants will grow on the replica plate. This means that the colonies on the master plate, at precisely the same locations, must be antibiotic-resistant mutants. These colonies can be picked up and subcultured. After a couple of repetitions of the procedure, one can be sure that there is an antibiotic-resistant mutant that has not been exposed to the antibiotic anytime. The bacteria we expose to the antibiotic are the siblings of these cells. This in essence is the bacteriological version of 'sib selection'. When one can get antibiotic-resistant mutants without exposure to the antibiotic, it means that mutations are not a response to the selective agent but they arise spontaneously.

Cairns et al found that what the Luria-Delbruck and the Lederberg experiments proved was only that at least some of the mutations were spontaneous. Their experiments did not prove that all mutations were spontaneous.

These two celebrated experiments laid the foundations of bacterial genetics and their conclusions remained unchallenged for almost four decades. They became and remained the strongholds of neo-Darwinism. People believed that this was the final proof for all mutations being random. Little wonder therefore that a paper appearing in *Nature* in 1988 which challenged their conclusions stirred a hornet's nest.

A Unicorn Appears

Cairns, Overbaugh and Miller, in their paper, argued that both Luria-Delbruck as well as the Lederbergs were unfair to *E. coli*. They did not allow the organisms to show what they could do if given a decent chance. Luria and Delbruck used a bacteriophage which would kill the cells instantly as a selective agent. We know today that a mutation conferring resistance to phage is expressed only after several generations, a phenomenon called *phenotypic lag*. Therefore even if mutants had appeared after exposure to the phage they wouldn't have survived. The same applies for resistance to many of the antibiotics including streptomycin which the Lederbergs had used. We can of course forgive Luria-Delbruck and the Lederbergs on the grounds that in the early 1940s they did not know the molecular mechanism of phage or antibiotic resistance. In the light of the ever-increasing knowledge of the molecular mechanisms of mutations, someone ought to have reexamined the experimental logic. When Cairns et al did that, they found that what the Luria-Delbruck and the Lederberg experiments proved was only that at least some of the mutations were spontaneous. Their experiments did not prove that all mutations were spontaneous.

That was simply great. Not only did the organisms know when they needed to mutate, they also knew which gene to mutate.

Cairns et al then designed a different set of experiments. The statistical design of the experiment was similar to that of Luria-Delbruck, but instead of using a bacteriophage, they challenged *E. coli* with an environment that did not support the growth of the strain but did not kill it instantly. Now the

So unorthodox and unexpected was Cairns' report that Stahl called it "A Unicorn in the Garden".

cells had ample time to sense the environment and develop the appropriate mutations, if at all they had the capacity to do so. Here the culture used was a mutant of *E. coli* unable to utilize lactose (called lac$^-$) and it was plated on a medium containing lactose as the only source of food. Now if mutations that reverted back to lac$^+$ arose as a result of exposure to lactose, their frequency distribution should have been Poisson. On the other hand if mutations took place before starvation, one would get a Luria-Delbruck distribution. What Cairns et al actually obtained was a composite distribution indicating that both types of mutations might be taking place. The revertant colonies did not appear all at once but accumulated slowly over a period of more than a week. Every day new mutant colonies were observed on the plates suggesting that the starving cells were still mutating after a few days of incubation. Further studies on the rates of specific mutations showed that under the above conditions the rate of lac$^-$ to lac$^+$ mutation had specifically increased. Rates of other mutations which offered no selective advantage did not so increase. That was simply great. Not only did the organisms know when they needed to mutate, they also knew which gene to mutate.

This came as a shock. Franklin Stahl, in the same volume of *Nature* exclaimed, "What's up? Can bacteria really direct their mutational processes? Did bacteria discover 'directed mutagenesis' before the genetic engineers did?" So unorthodox and unexpected was Cairns' report that Stahl called it "A Unicorn in the Garden".

The First Wave of Reactions

Needless to say the paper created a sensation. A tide of reactions appeared in subsequent issues of *Nature*. A few researchers had noted similar observations before, which had confused them. They became bold and supported Cairns et al.

A host of others were skeptical and found many loopholes in the experimental design and also suggested alternative explanations for the results. Cairns' experiments did have some loopholes and the possibility of alternative explanations. If, for example, the growth rate of mutants was considerably lower than the wild type, an apparently composite distribution like the one obtained by Cairns et al is possible. It was also pointed out that the lac^- cells might be exhibiting slow growth on the lactose medium either because the mutant was leaky or because the lactose was impure. The resultant replication of DNA might allow accumulation of mutants. What might have really bothered the critics were the philosophical implications rather than the experimental design. Did the results support Lamarckism or any modified version of it? Or could the interpretation still be made within the framework of neo-Darwinism? The debate continued. This was but natural. Whenever a team of researchers reports something dramatically different from an existing paradigm it has to pass every scrutiny from all the skeptics of the world.

Whenever a team of researchers reports something dramatically different from an existing paradigm it has to pass every scrutiny from all the skeptics of the world.

But the results were reproducible. Confirmation of the findings followed from several laboratories. Leading among them was Barry Hall. Hall not only confirmed earlier results but tried to improve the experimental design in order to remove all the loopholes pointed out by the critics. Hall also made it clear that the phenomenon, which by now was variously named as 'directed', 'adaptive' or 'Cairnsian' mutation was not confined to the lactose locus but worked as well for a number of different loci and a number of different kinds of mutations many of them involving 'cryptic genes'. Cryptic genes are genes that are normally silent. In order to make these genes active, a specific mutational event is needed. In the case of the cryptic cellobiose utilization operon of *E. coli* it was seen that the frequency of a point mutation that activates the operon was high in an environment in which the gene product was needed.

Although it became increasingly clear that bacteria could really undergo directed mutagenesis, nobody understood the mechanism. Speculations started accumulating from the date of the very first report of directed mutations. But they remained speculations until mid-1995, when a couple of papers appearing in *Science* promised a breakthrough. In order to understand the mechanisms, we will have to peer a little deeper into molecular biology, which we had side-tracked in this article so far. A discussion of these aspects will be taken up in one of the future issues of *Resonance*.

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From Genetics to Genetic Algorithms

Solution to Optimisation Problems Using Natural Systems

Jitendra R Raol and Abhijit Jalisatgi

Genetic algorithms are search procedures inspired by natural selection and genetics that can be used to obtain global and robust solutions to optimisation problems. They find applications in computer science, engineering, economics, linguistics, psychology, biology, etc.

Robustness, the ability to strike a balance between efficiency and efficacy, is necessary for any system to survive in many different environments. Nature usually offers good solutions whenever robustness is required. Biological systems are more robust, efficient and flexible than the most sophisticated artificial systems. Artificial systems have to learn from biological ones to improve their performance and carry out their functions for longer periods of time. Genetic algorithms are based on principles drawn from natural systems.

Genetic algorithms (GAs) are computational optimisation schemes with an unconventional approach. They were developed by John Holland and his colleagues at the University of Michigan. The algorithms solve optimisation problems imitating nature in the way it has been working for millions of years on the evolution of life. Inspired by biological systems, GAs adopt the rules of natural selection and genetics to achieve robustness. Acting on the premise of survival of the fittest, a population of possible solutions is combined in a manner similar to the mixing of chromosomes in a natural genetic system. The fitter population members pass on their structures as genes (***Resonance***, Vol.1, No.1, p 40) in far greater quantities than less fit members. The net effect is evolution of the population towards an optimum.

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Genetic algorithms are based on principles drawn from natural systems.

GAs operate by combining the information present in different possible solutions for a given problem, in such a way that a better solution is obtained in future generations. Terminologies used in natural genetic systems (NGS) and (GAs) are given in the box below. Often NGS terminology is used freely in the description of GA.

Terminology in Natural Genetic Systems and Genetic Algorithms

NGS (biological system)	GA (artificial genetic system)
chromosome	string
gene	feature or detector
allele	feature value
locus	string position
genotype	structure
phenotype	parameter set, alternative solution, a decoded structure

The *strings* of artificial genetic systems are analogous to chromosomes.

Comparison of Natural Systems and GAs Terminology

Chromosomes are long stretches of DNA that carry the genetic information needed to build an organism (*Resonance*, Vol.1, No.1). The *strings* of artificial genetic systems are analogous to chromosomes. Chromosomes are composed of *genes*. Each gene is a unit of information that takes different values called *alleles* at different *loci*. In artificial systems, strings are composed of *features* or *detectors* that assume different values (0 or 1 in case of binary coding) located at different positions on the string. The total genetic package is called the genotype whereas it is called a structure in artificial genetic systems. In natural systems, the organism formed by the interaction of the total genetic package with its environment is called the phenotype. In artificial genetic systems, the structures decode to form a particular parameter set or a possible solution.

Operations in a GA

Parameters (Numeric Values)	String
6	000110
12	001100
34	100010
20	010100

Chromosomes : Chromosomes represent encoding of information in a string of finite length on which the algorithm operates. Each chromosome consists of a string of bits. Each bit may be binary 0 or 1, or it may be a symbol from a set of more than two elements. Generally for function optimisation problems, chromosomes are constructed from binary strings. A few examples of encoded parameters in a binary string of length 6 are shown alongside.

Population and Fitness : GAs operate by maintaining a population of such possible solutions with chromosomes. Population members are called individuals. Each individual is assigned a fitness value based on the cost function. Better individuals (solutions) have higher fitness values and weaker individuals (solutions) have lower fitness values. A simple GA is composed of the operations discussed next.

Chromosomes represent encoding of information in a string of finite length on which the algorithm operates.

Initialisation and Reproduction : A population of possible initial solutions is created by randomly selecting information from the search space and encoding it. Selecting the information means assigning random values to the decision variables of the cost function. Reproduction is a process in which individual strings are copied according to their fitness values.

Cost Function, Decision Variables, Search Space

In most of the practical optimisation problems, the aim is to find optimal parameters to increase the production and/or to reduce the expenditure/ loss, i.e. to get maximum profit by reorganising the system and its parameters. Since this will finally reflect on the cost, it is represented by the cost function (*Figure 1*). A carefully written and convergent computational algorithm (***Resonance***, Vol.1, No.1 'Introduction to Algorithms') would eventually find an optimum solution. The parameters of the system that decide the cost are called decision variables. The search space is a Euclidean space (***Resonance***, Vol.1, No.1 'Geometry: The Beginnings') in which parameters take different values and each point in this space is a possible solution of the problem.

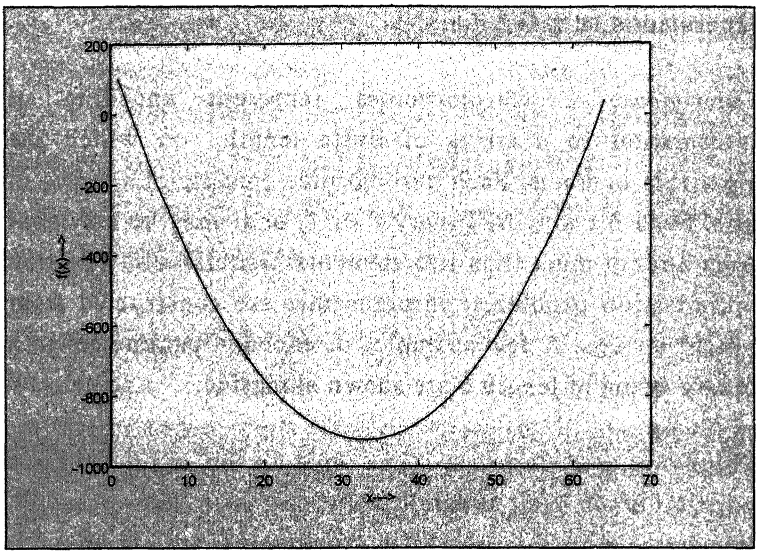

Figure 1 A cost function f(x) has x as parameter or variable which when optimally determined, will yield either maximum or minimum value of the cost function depending upon the nature of the problem. The function has a global maximum of 100 at x = 0. Also it has local maxima of 37 at x = 63 and minimum of –924 at x = 32.

This means that strings with a higher fitness have higher probability of contributing one or more offspring to the next generation.

Crossover : After reproduction, a simple crossover may proceed in two steps: i) members of newly reproduced strings in a mating pool are mated at random, and ii) each pair of strings undergoes crossover. In a crossover operation, a site is selected randomly along the length of the chromosome, and each chromosome is split into two pieces by breaking at the crossover site. The new chromosomes are then formed by joining the top piece of one chromosome with the tail piece of another (*Figure 2*). Thus as in natural genetics, the population members are allowed to mate in a probabilistic manner, with each combination producing offspring that are similar but not identical to both parents.

In simple GAs, a mutation is a random alteration of a value of the string position.

Mutation : A mutation operator is included in most GAs. In simple GAs, a mutation is a random alteration of a value of the string position. This operator helps to gain information that is not available to the rest of the population. The purpose of the mutation operator is to prevent loss of important information by effectively increasing the population diversity.

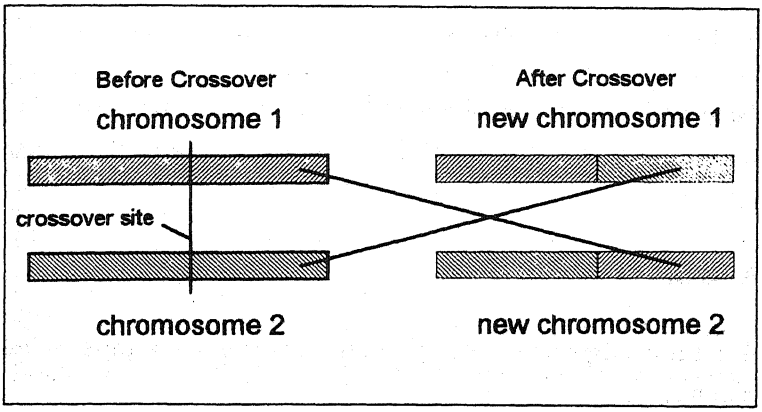

Figure 2 Crossover operation is exchanging the high performance notions to form new ideas in the search for better performance. This operation is included in GAs because it efficiently builds new ideas from the best partial solutions of previous trials

Generation : Each iteration in this optimisation procedure is called a generation. In each generation, pairs of individual chromosomes are chosen for crossover operation. The fitness determines the likelihood for reproduction and crossover probability for new offspring is applied to decide which individual will undergo crossover. Mutation is randomly carried out during the crossover operation (during or after has a subtle distinction). A new population evolves from these operations.

Survival of the fittest : The individuals may be fitter or weaker than other population members and must be evaluated and placed at their relevant ranked place in the population. This ranking process will involve some form of sorting routine that

GAs vs Conventional Search Methods

In conventional search methods, a point is chosen in a search space, and the next point is obtained using the gradient of the cost function at that point. One may get to the local peaks or troughs in multimodal search spaces (See *Figure 3*). Many search techniques require a lot of auxiliary information in order to work properly. For example, gradient techniques need derivatives of the cost function with respect to search variables {change in $f(x)$/change in x} in order to climb up (down) the current peak (trough) (*Figure 1*). GAs work simultaneously from a rich database of points, climbing many peaks in parallel. Thus the probability of finding a local peak is reduced as compared to other methods. GAs only require cost function values associated with individual strings, to perform an effective search for better solutions. They can be applied to a large range of optimisation problems that require cost function minimisation or maximisation.

is applied to each generation. In every generation the weaker members of the population are allowed to die out and only members who are fit take part in the genetic operation. The net effect is the evolution of the population towards the global optimum.

A Simple GA

A simple algorithm using binary coding technique is as follows:

1. Create population of N samples from a chosen search space – denoting the decision variables.
2. Produce series of 0s and 1s to create chromosomes – encoding the decision variables.
3. Calculate cost function values and assign fitness to each individual.
4. Sort the individuals according to respective fitness values and apply the reproduction operator.
5. Carry out crossover operation taking two chromosomes at a time.
6. Mutate the chromosomes during crossover with a given probability of mutation.
7. Replace weakest member of new population by the best member of old population.
8. Replace old generation by new population.
9. Repeat step 3 to step 8 for a given number of generations.

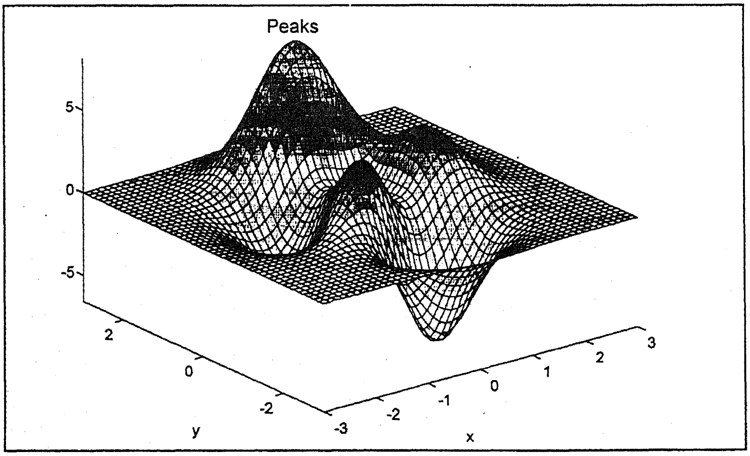

Figure 3 Multimodal function-surface has more than one maximum or minimum. The aim of a GA is to obtain the values of parameters that give a global optimum.

Simulation of a GA

Consider the problem of maximising the function *(Figure 1)*

$$f(x) = x^2 - 64x + 100,$$

where x varies from 0 to 63.

This function has a global maximum value of 100 at $x = 0$, as can be easily computed. To use a genetic algorithm, decision variables of the problem have to be coded in strings of finite length. For this problem, we can encode the variables as a binary string of length 6. We create an initial population with 4 samples by randomly selecting them from the interval 0 to 63 and encode each sample. A binary string of length 6 can represent any value from 0 to 63 (2^6–1); hence string length is chosen as 6 for the example. Four encoded samples in the initial population are:

5 = 0 0 0 1 0 1
60 = 1 1 1 1 0 0
33 = 1 0 0 0 0 1
8 = 0 0 1 0 0 0

These individuals are sorted according to their fitness values. (They are arranged in the descending order of their fitness values). In this case, the fitness value is the same as the cost function value. These sorted individuals are given as:

No.	x	String	Fitness
1	60	1 1 1 1 0 0	–140
2	5	0 0 0 1 0 1	–195
3	8	0 0 1 0 0 0	–348
4	33	1 0 0 0 0 1	–923

In the 1st generation, the 1st and 2nd strings are crossed over at site 3, (crossover site is randomly selected) to get two new strings:

To use a genetic algorithm, decision variables of the problem have to be coded in strings of finite length.

crossover site	new strings	fitness of new strings
111|100	111101	–83
000|101	000100	–140

Similarly the 3rd and 4th strings are crossed over at crossover site 2, to get:

crossover site	new strings	fitness of new strings
00|1000	000001	37
10|0001	101000	–860

Sorting these new individuals we get

No.	x	String	Fitness
1	1	0 0 0 0 0 1	37
2	61	1 1 1 1 0 1	–83
3	4	0 0 0 1 0 0	–140
4	40	1 0 1 0 0 0	–860

We see that in one generation fitness is improved from –140 to 37 ($f(1) > f(60)$). Before proceeding to the next step, the weakest member of the population is replaced by the fittest member of previous population, i.e., string 1 0 1 0 0 0 that has fitness –860 is replaced by string 1 1 1 1 0 0, whose fitness is –140.

In the 2nd generation, the 1st and 2nd strings are crossed over at site 1, to get:

crossover site	new strings	fitness of new strings
0|00001	011101	–915
1|11101	100001	–923

Similarly the 3rd and 4th strings are crossed over at crossover site 3 to get:

crossover site	new strings	fitness of new strings
000|100	000100	–140
111|100	111100	–140

Replacing the weakest member by the fittest member of the previous population (string 1 0 0 0 0 1 with fitness value of –923 is replaced by string 0 0 0 0 0 1 with fitness value of 37) and sorting them according to the fitness values, we get:

No.	x	String	Fitness
1	1	0 0 0 0 0 1	37
2	4	0 0 0 1 0 0	–140
3	60	1 1 1 1 0 0	–140
4	29	0 1 1 1 0 1	–915

In the third generation, the above process of crossover (at site=4) is repeated (not shown here). The new set of strings in the population, after replacement of the weakest by the fittest member of the previous population is given as:

No.	x	String	Fitness
1	0	0 0 0 0 0 0	100
2	1	0 0 0 0 0 1	37
3	61	1 1 1 1 0 1	–83
4	5	0 0 0 1 0 1	–195

For simplicity, the probability of the mutation is chosen as 0 (zero). We see that as genetic operations continue from one generation to the next, improved solutions evolve. At $x=0$, $f(x)=100$, which is the desired result. Here, the problem which could have been solved using conventional computational optimisation algorithms, is used to illustrate GA operations for the sake of simplicity.

Stopping Strategies

One can stop the search after a certain number of generations. However, for a fixed population size, more generations might be needed for convergence of the GA. The search can be stopped when no further improvement in fitness is detected. There are several types of stopping criteria and the research for an optimal criterion continues. Since GAs employ multiple concurrent search points, it is important to maintain the diversity of such points. A convergence criterion can be based on the assumption that as the GA progresses there will be a time when a large number of generations is needed to bring a small improvement in the fitness value. This can be ascertained from the gradient of a plot of best fitness against the number of generations needed to obtain that fitness. One can do an effective search if one exploits important similarities in the coding used in GAs. This leads one to the important notion of a *similarity template* or *schema*.

GAs Without Coding the Parameters

GAs become complex because of the efforts involved in encoding and decoding the chromosomes. Also they do not provide the variety of easy options, required to tackle the spectrum of problems faced in science and engineering which involve floating point numbers. For higher dimensional problems this leads to very long chromosomes. In such cases real number parameters can be directly used in genetic operations with some modifications in crossover and mutation operations. A crossover operation may involve only averaging of the information. A mutation is done by adding a small noise to the information. For a cost function varying with a parameter X, if 'A' and 'B' are two individuals with X_a and X_b as parameters, when they are crossed over, the new individual 'C' is created with parameter $X_c = (X_a + X_b)/2$. The best individual in population 'A' with parameter X_a will

undergo a mutation to create a new individual 'D' with parameter X_d, where $X_d = X_a + d_m \zeta$. Here d_m is a constant and ζ is a number chosen randomly between –1 to 1. In each generation the population is refreshed by taking new samples from the search space. A simple algorithm that does not code parameters can be obtained from the genetic algorithm described earlier, by incorporating the new crossover and mutation operations as discussed above.

Results of the application of a GA (without coding of the variables to the function of *Figure 4*) show that increase in the number of samples in the population, increases the success of reaching the global optimum. In this case the number of generations was 10 and the number of trials was 1000. The required accuracy was set to 0.0001. The percentage of success is defined as 100 times the number of trials in which the global minimum reached is divided by the total number of trials. For 15 samples the success was 100%. Some of these results have been obtained using NAL's parallel computer (Flosolver).

Concluding Remarks

Nature has been using GAs for millions of years and along the way it has produced complex, intelligent living organisms capable of reproduction, self–guidance and repair. Although

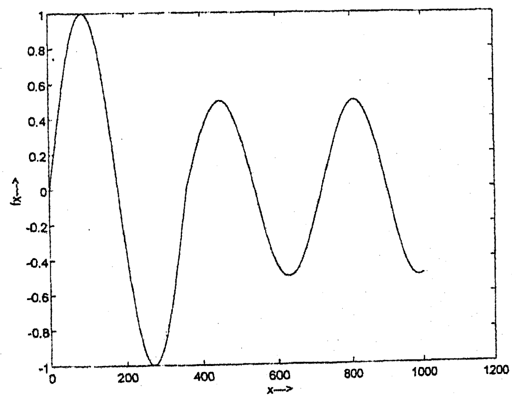

Figure 4 Function with more than one minimum. The aim is to search for a global minimum. Function: f(x) = sin(x), for 0<x<360; =[sin(x)] /2 for 360<x<1000. It has a global minimum f(x)= -1.0 at x=270. It has two local minima.

GAs are computationally simple, they have demonstrated their power and capability in optimising multi-modal, multi-dimensional and multi-objective problems. Hence they should find widespread applications in business, science and engineering. The price paid for global optimisation and robustness is the amount of computation required, which is not a problem in the age of fast/parallel computers. GAs use simple computational operations and yet are powerful tools for optimisation. Several versions/improvements in GAs are now emerging.

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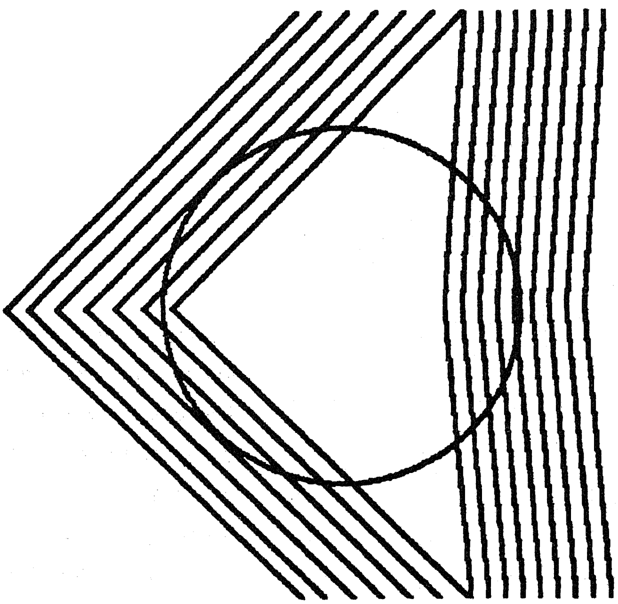
Suggested Reading

D E Goldberg. Genetic Algorithms in Search, Optimisation and Machine Learning, Addison-Wesley Publishing Company, Inc. 1989.

Zolliner Illusion



Cross hatching has resulted in an illusion of distortion in a perfect circle.

G S Ranganath

Antecedent Rivers

Ganga Is Older Than Himalaya

K S Valdiya

It seems like a case of the daughter being older than her father! For, the Puranas describe Ganga as the darling daughter of Himavant, the 'Nagadhiraja' or the king of mountains! (*Figure 1*). It so happens that the majority of Ganga's sisters – the rivers of the northern mountain realm – are older than the Himalaya in whose lap they were born.

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The Sindhu, Satluj, Ganga, Karnali, Kosi, Arun, and Brahmaputra rivers, among the scores of mountain rivers, had established their drainage networks well before the Himalaya came into existence as a mountain barrier. These rivers were past their youthful stage when the mountain ranges began rising across their paths.

What is the basis of the statement that these rivers are older than the mountains they cross?

Sources Beyond Highest Mountain Barrier

Practically all major rivers of the Himalayan province spring from sources lying beyond the highest mountain barrier – the

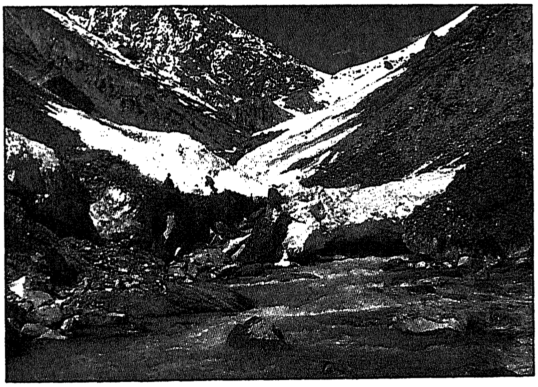

Figure 1 Snout of the Milam glacier – from which emerges the Gori, a tributary of the Kali (Ghaghara). It lies north of the NandaDevi (7,817 m) of the Himadri domain (the 'Daughter' and the 'Father').

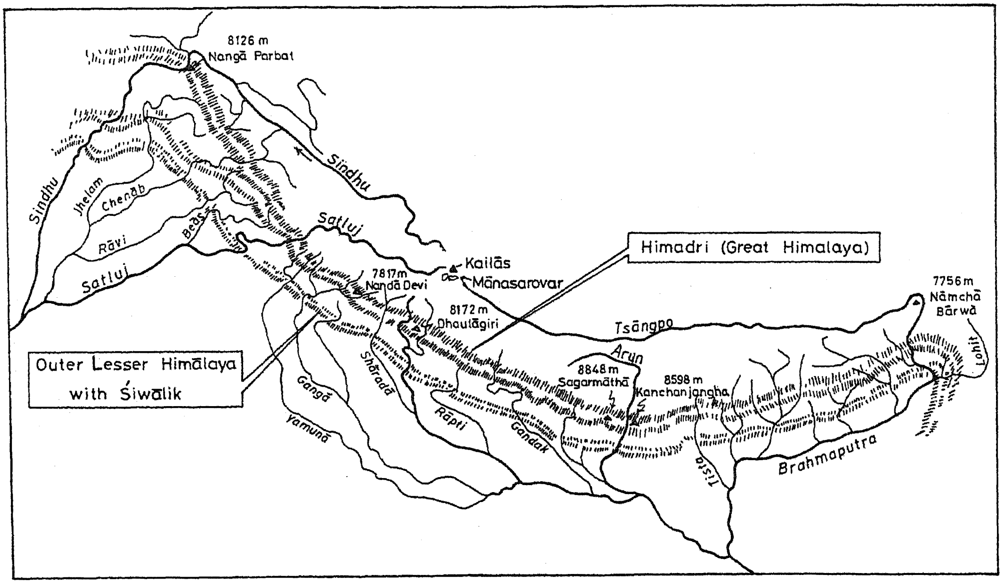

Figure 2 Himalayan rivers spring from sources located north of the highest mountain rampart (5,000-8,000 m or more) in the belt not higher than 4,500 m.

Himadri or Great Himalaya (*Figure* 2). The Himadri ranges rise to an elevation of 5,000 to 8,000 m or more while the river sources are located in the belt only 4,000 to 4,500 m above sea level. The waterdivide is thus at a level lower than the terrain through which the rivers have made their channels (*Figure* 3).

The rivers originating from the Kailas-Mansarovar region in southwestern Tibet (*Figure* 4) bear eloquent testimony. At the

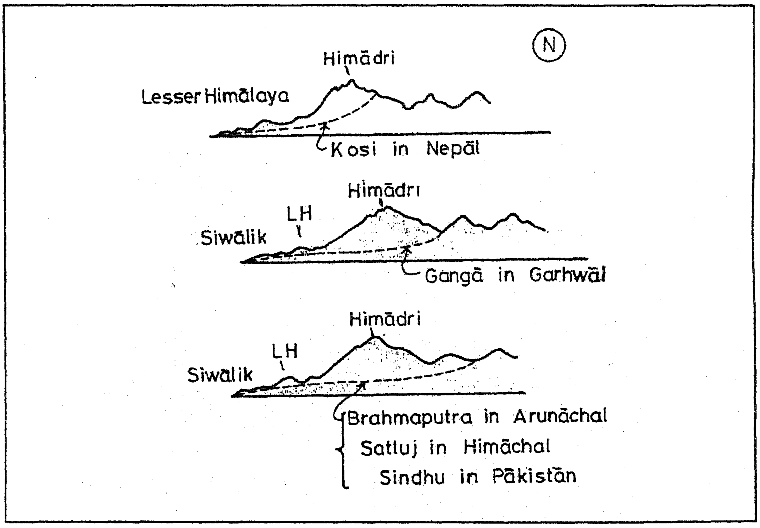

Figure 3 Majority of Himalayan rivers originate either on the northern flank of the Himadri (Great Himalaya) or the southern slope of the Indo-Tibetan border ranges. Notice the steep gradient in the uplifted Himalayan terrain.

foot of Mount Kailas (6,714 m) is Lake Mansarovar (4,557 m), far north of the high NandaDevi (7,817 m) – Api Nampa (7,132 m) range of the Himadri. The Sindhu flows northwestwards, the Satluj goes west, the Karnali takes the southerly course and the Tsangpo flows east. These rivers flow through their pristine channels, carved out at the very outset about 50 to 55 m.y (million years) ago. The Matsya Purana describes the descent of 'Divya Ganga' near Bindusar Sarovar (lake) nestling between the Kailas, Mainak, Hiranyashringa mountains, and taking three different paths as Tripathaga – the tripath gamini Ganga. The 'Tripathaga' had established the drainage well before the mountain barriers were raised successively as a result of tectonic movements.

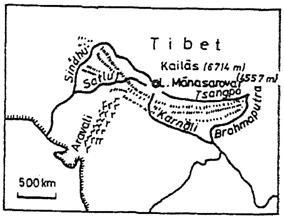

Figure 4 Sindhu, Satluj, Karnali and Brahmaputra have their sources in one region embracing Mount Kailas and Mansarovar lake. The 'Divya Ganga' of Matsya Purana took three paths as 'Tripathaga' – eastward as Brahmaputra (Tsangpo), southwards as Karnali and westwards as Satluj and Sindhu.

A significant feature of these rivers originating north of the lofty Himadri is that their beds are not more than 900 to 1,200 m above sea level at the points where they rush through the 6,000 to 8,000 m high mountain barrier (*Figure* 5). For example, southeast of Gilgit in northwestern Kashmir, the Sindhu flows on a bed 1,100 m above sea level, as the Nanga Parbat (8,126 m) looks down across a sheer wall more than 6,000 m high! Similarly, the Tsangpo in the east flows in the 5,000 m deep canyon cut through the 7,750 m high wall of the Namcha Barwa (*Figure* 3).

These rivers seem to have maintained their levels, while the mountain barriers rose higher and higher.

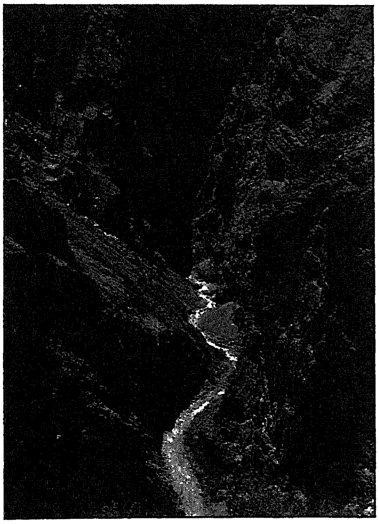

Figure 5 Canyon course of a tributary of the Ganga in Kumaun Himalaya. The more than 6,000 m high peak looks down on the bed of river flowing at 2,600 m level.

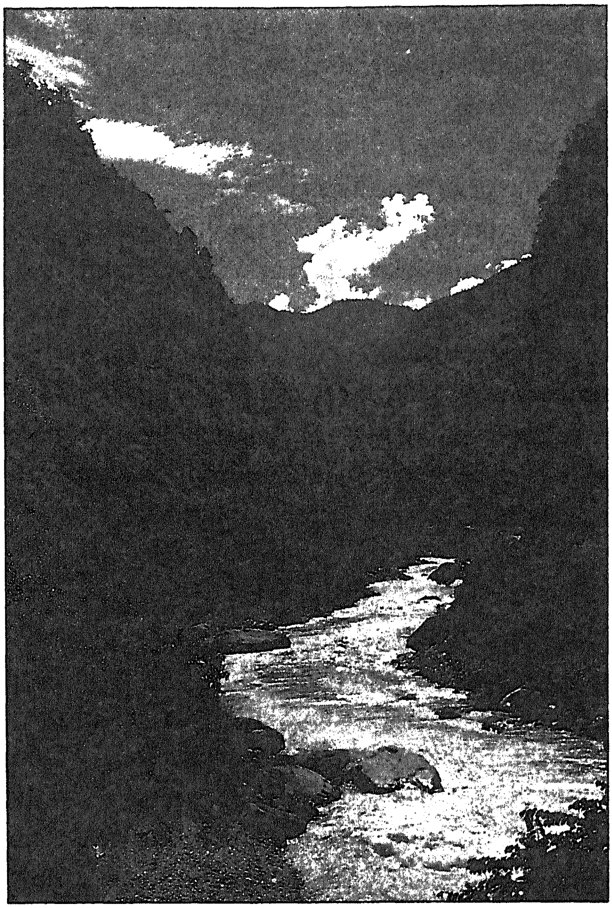

Figure 6 Steep gradient of the river in the Himadri domain characterized by rapids, cascades and waterfalls. Rivers Kali and Gori in Kumaun.

River Gradient

Wherever the mountain ranges are rising at a rate faster than the rivers are able to cut down their channels, waters plummet down as waterfalls and cascades or rush down furiously as foaming-roaring torrents.

Flowing between the Sagarmatha or Everest (8,848 m) and the Kanchanjangha (8,529 m) in northeastern Nepal, the Arun drops to 1,200 m from 4,333 m, through a fearsome gorge characterized by rapids and cascades. The antecedent rivers have low gradients of the order of a few metres per kilometre in their upper as well as lower reaches, where they flow sluggishly in their wide valleys in the trans-Himalayan belt in the north and the Indo-Gangetic plains in the south. However, as these rivers cross the Great Himalayan belt, the descent is of the order of 700 to 900 m for every 1,000 m of flow! In the Lesser Himalaya the gradient varies between 20 and 40 m per kilometre. The pronounced steepening of the

Figure 7 A The angle between the two slopes of the V-shaped valley is very acute. Locally the valley slope is convex. River Gori in Kumaun.

gradient of the rivers crossing the Great Himalayan barrier (*Figure 6*) means two things: The uplift of the mountain rampart has been accentuated and/or the uplift is a recent and continuing phenomenon. Wherever the mountain ranges are rising at a rate faster than the rivers are able to cut down their channels, waters plummet down as waterfalls and cascades or rush down furiously as foaming-roaring torrents.

Figure 7B Diagrammatic sketch of an incised valley. The incision or deep cutting is due to uplift of the terrain.

Steep Valley Slopes

The slopes of valleys in the stretches through the Great Himalaya (Himadri) and the outer (southern) front of the Lesser Himalaya are very steep, practically vertical in some sectors (*Figure 7*). It may be mentioned that as the rivers grow

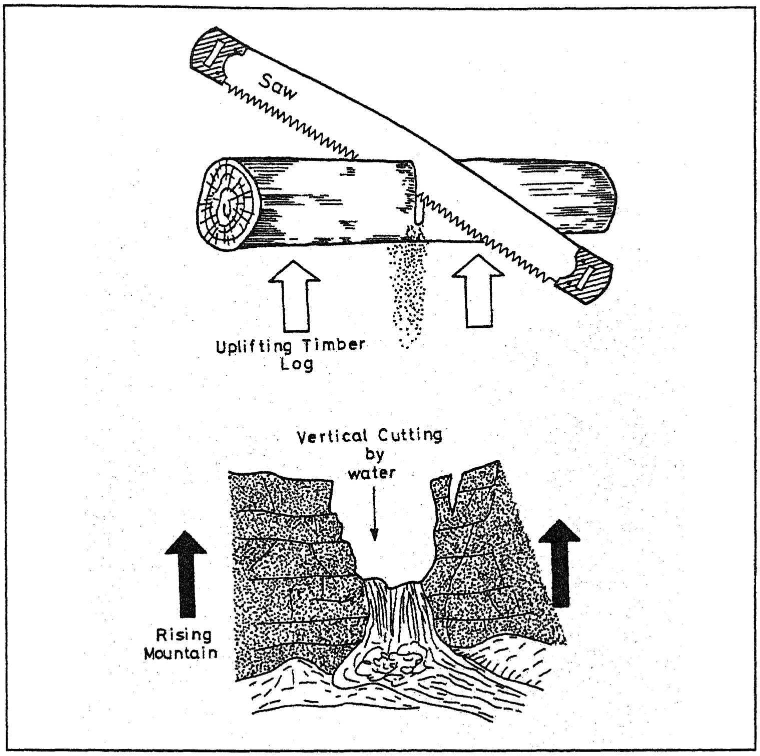

Figure 8 Imagine a log of wood raised slowly as the saw cuts through a constant level or axis. The result is a vertical groove with two parallel sides. In a similar manner the river cuts a deep canyon with practically vertical walls (valley slopes).

older and become mature (geomorphically), their valleys become wider with gentler slopes. The angle between the two slopes becomes increasingly obtuse with advancing age. However, this angle in the Himadri and PirPanjal – Mahabharat belts (in the outer Lesser Himalaya) is very acute. In some places, the valley slopes make nearly parallel vertical walls, despite the rivers being 50–55 m.y old. Locally the walls are convex. Obviously, in spite of the great age the rivers are still in their (geomorphically) youthful stage, furiously at work, cutting channel beds, eroding slopes, and denuding watersheds. This ever-youthfulness of the Himalayan rivers is an inherent character due to the continuing uplift of the terrains through which the rivers flow (*Figure 7*).

These rivers established their drainage not consequent on the province's physical atures as we see ɣ, but following elief and slope ɔf the land that ‹sted before the mountain was rmed. Such rivers the Sindhu, Satluj, Karnali, Arun and Brahmaputra are :herefore called the antecedent rivers.

Understandably, as the Himalayan terrain rose progressively, the rivers kept cutting their courses deeper and deeper. Over the long period of millions of years, deep gorges or canyons

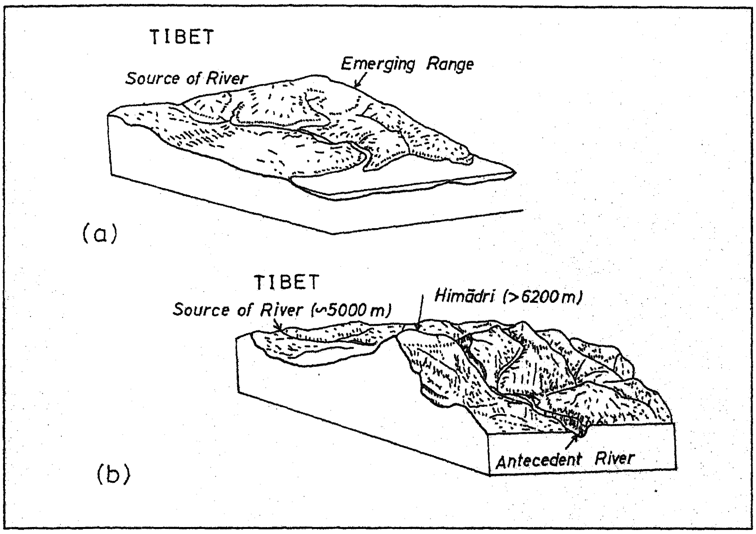

Figure 9A A river establishes its drainage on the recently emerged land that sloped gently southwards.

9B Much later, the mountain barriers rose slowly, and the river kept its channel open by cutting down its course deeper and deeper. This is an antecedent river.

with nearly vertical walls developed in the stretches of impediments (*Figure 7B*). Where the mountain barrier rose at a much faster rate and the rivers failed to keep pace, they dropped in waterfalls and cascades.

Why is the Himalayan terrain rising?

Tectonic Development: Birth of Mountain Ranges

The northward moving India collided with Asia nearly 65 m.y. ago, and the process of welding of the two continents was completed by the Lower Eocene epoch nearly 55 m.y. back. As the Indian landmass pushed northwards, the junction of the two continents buckled and ridged up. The elevated upwarp became the waterdivide of the rivers and streams that came into existence during that period in the pre-monsoon climate. The radial drainage of the soil of the Sindhu, Satluj, Karnali and Brahmaputra rivers was established (*Figure 4*) on that newly emerged land. These rivers established their drainage not consequent on the province's physical features as we see today, but following the relief and slope of the land that existed before the mountain was formed. Such rivers as the Sindhu, Satluj, Karnali, Arun and Brahmaputra are therefore

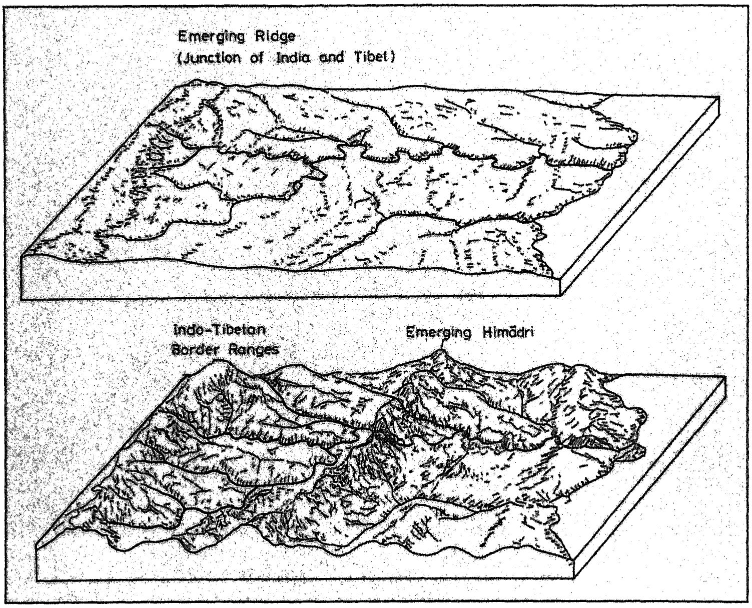

Figure 10 This is what the Himalayan country must have looked like before and after the main tectonic upheaval that gave birth to the Himalaya mountain.

called the antecedent rivers. They were flowing through their winding or even tortuous channels in the land that sloped southwards very gently (*Figures 9* and *10*). They continued to flow in the same directions through their old channels even when mountain barriers formed across their paths. The Himalaya rose, but slowly.

Subsequent to the emergence of the Himalaya there was a resurgence of severe tectonic movements. There was a very severe revival of the mountain-building activity about 1.7–1.6 m.y ago.

Then came the climactic, the dramatic phase of the tectonic revolution which threw the whole of northern India into convulsions of deformation. The rock piles were severely compressed and broken. Folds after folds were formed, then faulted along their axial planes and dislocated or uprooted tens of kilometres. Repeated deformation of rocks was accompanied by their differential melting in zones of severe and deep-seated deformation; and widespread granitic activities (25 to 15 m.y. ago) strengthened the structural framework of the Himalaya, particularly in the Himadri domain. In this way the stupendous mountain ranges developed through the middle of the province. In this way, about 25 to 20 m.y. ago emerged the Himalayan mountain in its grandeur and uniqueness. The rivers continued to flow in

the courses they had carved out at the outset, but deepened their channels progressively (*Figure 9*).

Subsequent to the emergence of the Himalaya there was a resurgence of severe tectonic movements. There was a very severe revival of the mountain-building activity about 1.7–1.6 m.y ago. The outer southern front of the Lesser Himalaya was lifted up into the lofty rampart comprising PirPanjal-Dhauladhar-Naina-Mahabharat Ranges, and the Siwalik ranges came into existence. The rivers made still deeper incisions, kept open their channels, and retained their youthfulness. But their gradients became steeper, their valleys deeper and narrower in their lower part, and they rushed through their gorgeous courses characterized by rapids.

These phenomena are seen in all the mountain belts which have risen and gained height in geologically recent times. The Kaveri river, for example, exhibits many of the characteristics of the antecedent drainage in the Biligirirangan Ranges which the Ganga shows in the Himalaya.

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Fungus of Good Fortune ? ...

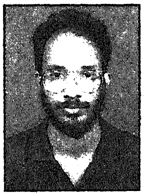
A small culture of *Penicillium notatum*, mounted in a glass slide, recently fetched £23,000 as a collector's item and must surely rank, on a weight-for-weight basis, as one of the most expensive commodities ever to change hands! It is one of only two or three such preparations by (Sir) Alexander Fleming, dating from about 1948 and bearing as a hand-written inscription 'The mould that makes penicillin', with his name. The international company Pfizer, which assisted Fleming in the development of his discovery, were the buyers.

Mycologist

Nature Watch

Secrets of the Shieldtails

Kartik Shanker



Kartik Shanker spent two years in the Upper Nilgiris studying small mammal and herpetofaunal communities. His interest in snakes was inspired by the 'snake catching' Irula tribe near Madras.

Shield tails are a group of snakes belonging to the family Uropeltidae, endemic to the Western Ghats and Sri Lanka. They are small, beautiful non–poisonous snakes with bright colours, found at high altitudes in the 'shola' forests. They spend much of their life burrowing 1–2 metres beneath the surface, in search of their favourite food, earthworms. Loss of habitat has been a major cause for their decline and many of the species may now be endangered.

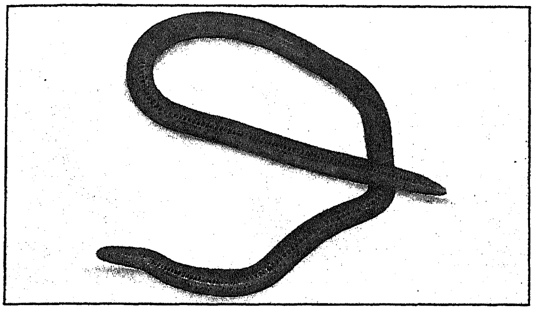
Introduction

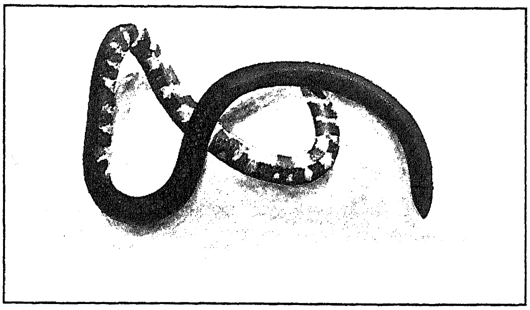
The Western Ghats are well known for their biodiversity; much has been written and said about their wide array of plants and animals, especially the high degree of endemism and the rare and endangered mammals. Less however is known about the herpetofauna (amphibians and reptiles) of these hills. There are 117 species of amphibians, of which about 90 are endemic. Some, like the tree frogs found in the higher altitudes, are poorly studied. However, the least known amongst the unique fauna of the Western Ghats may well be the *shieldtails*.

The shieldtails are a group of non-poisonous snakes belonging to the family *Uropeltidae*.

The shieldtails are a group of non-poisonous snakes belonging to the family *Uropeltidae*. These snakes are found in the Western Ghats and Sri Lanka and nowhere else in the world. There are about 45 species belonging to 7 genera, of which 35 are found in the Western Ghats. They are highly colourful snakes, and each species has its own distinct marking.

Uropeltids are found in the higher reaches of the Western Ghats, usually at 1500 metres or higher. They inhabit the





shola forests, which are the natural vegetation of the area. However, they are also found in the different plantations which have become a common feature of the hills. Uropeltids have evaded extensive study because of their excessively secretive nature. They burrow 1 to 2 metres below the soil, and stay there for much of the year, emerging only during the rainy season to mate. Besides, they are also nocturnal which makes them even more difficult to observe.

Figure 1 The genus Uropeltis has 19 species, the most amongst the uropeltids. The species are widely distributed over the Western Ghats, Eastern Ghats and in Sri Lanka.

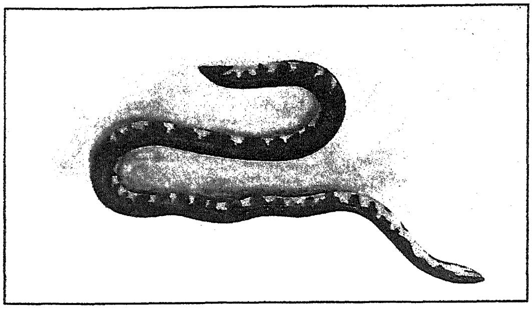
Figure 2 Uropeltis pulneyensis: This species is found in the Palanis and the hills of South Kerala. The snakes are often found beneath the muddy black soil on the edges of hill streams in and around Kodaikanal.

Montane Homes

Uropeltid snakes are generally found in areas of high elevation and low temperature. The Western Ghats, where most of the uropeltids are found, have a short dry season of 3 to 4 months followed by rains from the Southwest monsoon and the Northeast monsoon. Rainfall seems to limit the distribution of the shieldtails, because it affects the development of forest vegetation. The vegetation in the upper reaches of the Western Ghats is of the *shola-grassland* type. The sholas are tropical montane–stunted evergreen forests, which are surrounded by grasslands. These grasslands are spotted with *Rhododendron nilagiricum* and also feature riverine tracts. The uropeltids are found largely in the forests.

> Uropeltids are found in the higher reaches of the Western Ghats, usually at 1500 metres or higher. They inhabit the shola forests, which are the natural vegetation of the area.

Much of the habitat in the Western Ghats has been replaced by plantations of tea, wattle, pine and eucalyptus. Tea plantations were first introduced by the British and have taken over much of the landscape over the past 150 years. In the last 50 to 100 years, the forest departments have shown



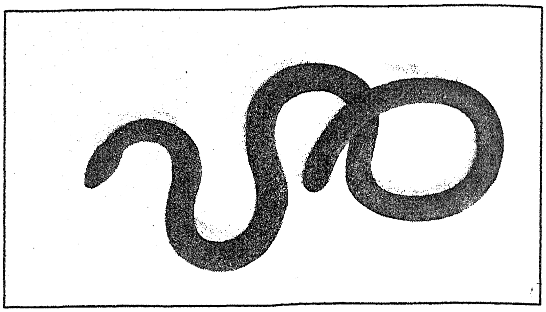


Figure 3 Uropeltis ocellatus: ***This species is common in the Nilgiris and Anamalais. It appears to have adapted to different habitats, including cardamom plantations. In Anamalais, they were dug out of clay soils, clinging to tubers in inundated fields.***

Figure 4 Uropeltis ceylanicus: This species has three different colour forms. It is one of two species whose range extends to the eastern ghats. The other is Uropeltis ellioti.

some concern about the protection of the sholas, but the grasslands have been largely ignored, and many of them have been replaced with wattle plantations.

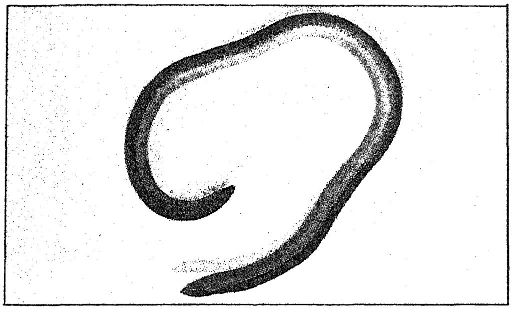
Painting a Picture

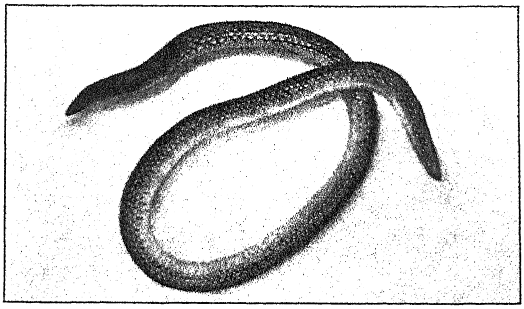
Uropeltids are small, fossorial, uniformly cylindrical snakes with a tapering head and tail. They are about 30–50 cm long and could, in fact, be mistaken for large earthworms, but for their flashy colours. The conical head has a keratinised tip and is slender, pointed and round in cross–section. The tail is short and blunt and in fact, they are also called 'rough tailed snakes'. The tail has a single enlarged and roughened shield, which may be fringed with less modified scales. The skin is superficially smooth and the scales are shiny and iridiscent, showing a spectrum from blue to orange. Most of the uropeltids have a black, brown or olive green dorsal surface. They have light or brightly coloured lateral lines or blotches, especially on the tail or the neck. The source of the pigments is within the integument. These features are believed to be highly adaptive to their lifestyle. Most uropeltids are extremely beautiful snakes, but their marvellous colours arouse both admiration and fear.

Uropeltids are small, fossorial, uniformly cylindrical snakes with a tapering head and tail. They are about 30–50 cm long and could, in fact, be mistaken for large earthworms, but for their flashy colours.

An Adaptationist Eye View

Uropeltids are essentially earth snakes living beneath the soil. Their 'wedge shaped head' serves as their 'tunneling device'. The keratinised ridge facilitates penetration and serves to





distribute stress. The head, led by the tip, drives a primary tunnel and the anterior vertebral column, with its S-shaped curvature, provides second stage widening. The snake's mode of tunneling is well suited for travel among root systems. As the uropeltids do live in tropical forests with a high density of woody plants, the soils are likely to have complex root systems and this adaptation becomes significant.

Figure 5** Brachyiophidium rhodogaster:* ***This genus has a single species. It is found in the Palanis. It is usually found in humus and other decayed vegetable matter.

Figure 6** Plectrurus perroteti:* ***This shieldtail is common in the Nilgiris and Anamalais. It has been observed that the specimens found in sholas where they occur naturally are usually a uniform brown.

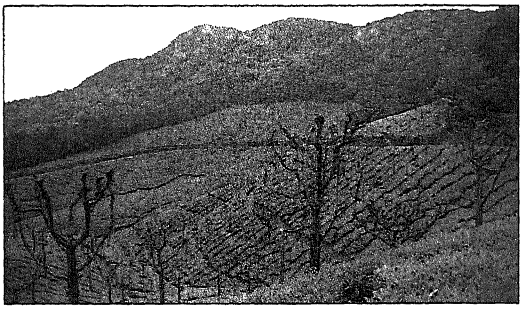
These burrows are constructed during the rainy season, when the soil is soft. The burrows then harden, and the snakes wander in their network beneath the soil in search of their food, earthworms.

The *shield* on the tail helps form a plug to close the tunnel. Many shieldtails, when removed from the soil, have been found to have dirt capped caudal shields. The plug should serve to confuse and deter predators of the snakes.

The *chemical colours* of the snakes are produced by the chromatophores in the dermis. These could be explained by different adaptive arguments such as *flash colouration*; predators tend to avoid bright or flashy colours as these are usually indicative of poisonous animals. Another explanation for the colours could be head mimicry.

The *chemical colours* of the snakes are produced by the chromatophores in the dermis.

The *coiling behaviour* of the shieldtails is interesting in this context. When excavated, they coil immediately around one's fingers or any available object, and rigidly project their tails. This must also happen when they are burrowing. The tails'



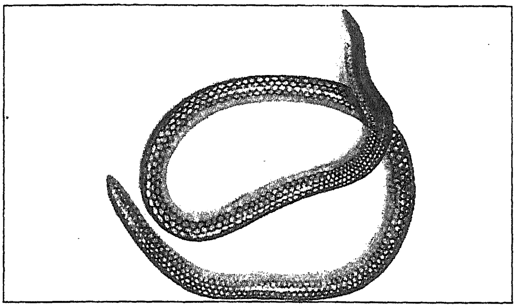


Figure 7 Plectrurus perroteti: ***The same species, when found in tea estates and plantations (and in sholas in some areas), is reddish below. Juveniles often have a yellow line on the dorsal surface of the tail.***

Figure 8 Thai Shola is the largest patch of montane evergreen forest in the Nilgiris. It adjoins a large tea estate; estates have been responsible for substantial habitat loss in the upper plateau of the Western Ghats, adversely affecting the uropeltids.

rhythmic movements, coupled with the lateral eyespots enhances its similarity to the head.

The colour pattern of the snakes may also resemble some of the small elapid snakes of Sri Lanka. Although these venomous elapids are now too rare to suggest mimicry, the distributions of these snakes may have been greatly affected by agricultural advances in recent times. It is also suggested that the uropeltid colouration mimics that of some poisonous arthropods such as centipedes. The venomous coral snake, *Callophis nigrescens*, also occurs at a number of localities in the Western Ghats where uropeltids are also found. Though they share the cylindrical body and short tail, Callophis is much longer than uropeltids, and has a different colouration. However, one uropeltid, *Platyplectrurus trilineatus*, has a colouration similar to the coral snake.

Finally the *structural colours* of uropeltids may also be adaptive. They have an axially oriented stripe pattern. Such regular patterns are believed to help in the reduction of friction. In uropeltids, they may serve to keep particles from sticking to the surface and also as an anti-wetting device.

Earthworms seem to form a major part of the uropeltid diet. Stomach content analysis has shown that earthworms form 80-90 % of their diet.

In the Food Chain

Earthworms seem to form a major part of the uropeltid diet. They may take small quantities of earwigs, termites and caterpillars, but these are not significant. Stomach content analysis has shown that earthworms form 80–90 % of their diet.

:oupled with the fact that uropeltid distribution is closely related ɔ the presence and absence of earthworms, earthworms would ppear to be an important part of their ecology.

Jropeltids are often killed by boars, which encounter them vhile digging for tubers. Mongoose may also eat these snakes. irds, such as domestic fowl, pea fowl, jungle fowl and owls of arious kinds feed on uropeltids.

'hough uropeltids are known to be ovoviviparous, little else known about their breeding and reproduction. Normal lutches seem to have 3 to 8 eggs, but there is a record of a oecimen with 9 embryos. Development takes place in one viduct, usually the right one.

Figure 9 Montane evergreen patches or 'sholas' can be as small as half a hectare and uropeltids, being burrowing snakes would tend to be restricted to their patches.

Figure 10 Sholas are usually found in valleys. They are bordered by species such as *Rhododendron* and *Syzygium*.

arl Gans studied allozymes, which are different lectrophoretic forms of the same enzyme, at a number of enetic loci to evaluate genetic distances between the ropeltids genera and species. He also investigated variation ı serum albumin in these taxa using immunological echniques. By this method he found uropeltids to be *enetically highly differentiated.* The phylogenetic tree most onsistent with the immunological and electrophoretic data ıowed the Sri Lankan snakes to be monophyletic, and the ıdian snakes to be paraphyletic with respect to those from ri Lanka. A biogeographic scenario seems to indicate an ırly diversification in India, followed by an invasion into the wlands of Sri Lanka. Subsequently, the uropeltids evolved Sri Lanka to occupy montane biotopes there.

Suggested Reading

C Gans. Aspects of the biology of uropeltid snakes. In *Morphology and Biology of Reptiles* A.d'A. Bellairs and C.B.Box (Eds). Linnean Society Symposium Series. Academic Press, London. 3: 191-204. 1976.

M V Rajendran. Studies in Uropeltid Snakes. Madurai Kamaraj University, Madurai. 1985.

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Conservation

Uropeltids are a part of the rich array of fauna of the Western Ghats. Their importance is heightened by the high diversity within the group and their endemism. Many species have highly localised distributions, making them even more vulnerable, as local extinction would mean the extinction of the species. The decline of uropeltids in recent years may be attributed to the spread of plantations in the Western Ghats. Their habitat has been destroyed and the few remaining areas are highly fragmented. These snakes are also killed by humans, as the hill people believe they are poisonous.

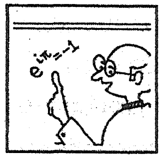
Uropeltids could be performing important ecological roles; they are able to burrow in extremely hard soils, creating a complex network of tunnels. It is likely that these allow free passage of air to the deep soil and supply atmospheric air to the roots and rootlets of shrubs and trees.

Much of the credit for our present knowledge of uropeltids should go to the late Professor M V Rajendran, who pioneered studies in the basic biology and ecology of these snakes. However, it is quite clear that a lot more research needs to be done on this unique group of snakes. It is also evident that they need to be made a conservation priority if we are to preserve an irreplaceable part of our heritage and an important component of the montane ecosystem of the western ghats.

Figure 11 Hillstreams cut deep valley between the hills and sholas are usually found in these valleys. There are smaller perennial streams running through all the sholas. Some species of shieldtails are found in the damp soil near streams.

Figure 12 Sholas are dense forests, with stunted trees usually, a high density of shrub vegetation. The canopy cover is high and very little light seeps through. The shola forest floor is covered with leaf litter and fallen logs.

Classroom



In this section of Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.*

! How Stimulating Ideas Can Generate An Attitude of Inquiry

From Girish Govindarajan and Emmett L Wright, Kansas State University, Kansas, USA.

Discrepant events are phenomena that occur or run contrary to our natural line of reasoning. In this article we highlight how such phenomena can be used to promote inquiry-oriented science learning in the classroom.

Introduction

The organisation of scientific information depends on the ways humans comprehend and classify knowledge. Accordingly, four major types of scientific knowledge are generally recognised: organisational knowledge, relational or interactional knowledge, inferential knowledge, and applied knowledge.

Many important aspects of the way we live can be, and are, affected by science and technology. Our attitudes, beliefs, ethics, and practices are equally affected by scientific knowledge. Science, as it is applied, benefits from advances made in technology; and technology, in the modern sense,

To be successful in reaching all types of students the science teacher must possess a great reservoir of stimulating ideas to generate an attitude of inquiry.

depends on scientific discovery. When such knowledge is taught to science students in a graded manner according to their degree of curiosity and receptivity, it could well motivate them to become contributing scientists. Some of the important requirements to achieving this include curiosity, an inherent interest to understand the natural world, an inquiring mind, and the determination to work long hours. To be successful in reaching all types of students – highly motivated, self-starters, slow, bored, truant, or plain disinterested students – the science teacher must possess a great reservoir of stimulating ideas to generate an attitude of inquiry. And, discrepant events work best. The ideas generated might come from hands-on examples and/or minds-on examples, based on natural discrepant events. In the hands-on examples, activities are designed around those discrepant events that students can manipulate and gain experimental knowledge from. The minds-on examples serve to consistently stimulate the mind of both the self-starter student and the bored/disinterested student to develop an attitude of inquiry.

Motivation in the Classroom

What, exactly, is a discrepant event? A discrepant event is a phenomenon that occurs or runs contrary to our natural line of reasoning. There are many scientific phenomena in the natural world that are often classified as anomalies and shrouded with ambiguity and uncertainty. In the students' (and, ours, too) daily life, learning science concepts often involves confronting natural discrepant events. For instance, we presented the following set of statements to undergraduate science students asking them to mark the statements as true or false.

- A gaseous white ring around the moon more often than not foretells precipitation.
- That the moon appears larger on the horizon than when overhead is an illusion.
- When meteorites hit the Earth they are extremely cold – not hot.

- During a tornado, windows tend to blow outward – not inward.
- Humans can skate on ice because ice is slippery until very low temperatures are reached.

Most students evaluated each statement as false. When we told them each statement was true, lengthy and heated discussions followed among the students. We succeeded in getting them involved, very interested in the inquiry, and very willing to discuss and share ideas. When the students are intrigued by the observed discrepancy in the discrepant event (see *Table 1* for some additional examples), they will be motivated to resolve the conflict between their own interpretation (assuming that it is non-scientific) of the event and the observed discrepancy. Some students may be dogmatically 'deep-seated' in their views. But, they will quickly realize that the new experience requires a depth of understanding of the problem as well as an evaluation of the validity of their knowledge of science concepts and principles.

In the disinterested students, both the curiosity and latent talent are awakened from their deep slumber with activities that captivate their senses, sustain motivation and imagination, and promote a deep desire to learn more.

This is an excellent opportunity for teachers. They could guide the student towards successful learning and testing of hypotheses through carefully designed experiments. To reduce the likelihood of learners quitting the learning experience, we recommend that the teacher: identify perceptions; provide new encounters which are motivating and allow for first-hand exploration; ascertain which existing ideas students are linking to and the aspects of the encounter they focus on; challenge incorrect or inappropriately reasoned ideas; recognise when students are playing guessing games ('false accommodation'); provide opportunities for students to practice applying new ideas; and, if necessary, provide them with remedial assistance.

Helping Students Overcome Misconceptions

Why is using discrepant events in instruction a viable pedagogical method? First, drawing students' attention to

Table 1. Examples of Discrepant Events.

Phenomenon, Event, Question, or Statement	Probable Student Response	Conceptual Discrepancy	Scientific concept or Principle Illustrated by Conceptual Discrepancy
The electric eel (Electrophorus electricus) is a true eel.	True	False. The electric eel is a freshwater fish and grows to a length of 2 to 4 metres. Researching the animal's ability to produce electricity will yield interesting information for further study.	More closely related to the carp and catfish than to eels, the electric eel is capable of delivering an electric shock of 500 volts when alarmed; a lower range of 60 to 100 volts is used for navigation. The animal is not a true eel because it has to surface very often to obtain oxygen from the air for respiration.
Amber is a mineral and a gem of great value.	True	False. Amber is not a mineral but can be a gem. As for its value, there is nothing great about it. However, some interesting properties and applications of amber are widely known.	Amber is a hard, translucent, yellowish-brown resin of fossil pine trees. Considered to be a good electric insulator, amber is also known to have the property of preserving the fossil remains of prehistoric insects. The insects were probably caught in the sticky resin, trapped, unable to escape, and died. The translucence of amber makes the study of trapped insects, and also preserved specimens of ancient plant leaves and parts, crystal-clear and fascinating in their original form.

conceptual discrepancies provokes them to display their natural curiosity about how the natural world works. This initial inquiry motivates them to become involved in learning activities and to develop logic-based explanations for the cause of such events. Particularly in the disinterested students, both the curiosity and latent talent are awakened from their deep

slumber with activities that captivate their senses, sustain motivation and imagination, and promote a deep desire to learn more.

Second, surfacing, identifying and classifying students' misconceptions are made very easy. As a result we could then use appropriate examples to help students overcome their misconceptions.

While teaching some new concepts or principles might prove a daunting task, correcting a misconception could be much more difficult. Understanding how students respond, when their current beliefs about the physical world conflict with information presented during science instruction, is critical for two reasons. First, encountering contradictory information is a very common occurrence in learning science. Second, students typically resist giving up or modifying their pre-instructional beliefs (especially, irrational ones).

Understanding how students respond, when their current beliefs about the physical world conflict with information presented during science instruction, is critical.

In recent times, deep processing and reflective theory change have been suggested in science education research literature, as avenues through which teachers could help students overcome misconceptions. Deep processing involves fostering personal involvement in the discrepant data issue, and ensuring that students justify their reasoning. Reflective theory change encourages students to reflect on their pre-instructional beliefs and change their incorrect theory in light of scientific reasoning.

We present here a few guidelines for science teachers keen on helping students deal with discrepant events and overcome misconceptions in their learning of science.

A. Influence Prior Knowledge

- Reduce the degree of entrenchment ('deep-seatedness') of students' prior theories;

Even though examples of discrepant events cannot be developed for every topic or scientific principle, teachers should remember that the event is used as an incentive to student involvement.

- assist students in constructing appropriate rational categories (ontological categories: the class of beliefs about the fundamental categories and properties of the world); faulty ontological beliefs include, for instance, (most) children's notion that the largest fish is the blue whale. In essence, they do not seem to acknowledge the fact that the whale is a mammal and not a fish;
- foster appropriate epistemological commitments (beliefs that are relatively immune to change because they are used to support ideas in many different subdomains); and,
- assist students as they build their fundamental knowledge.

B. Introduce the Alternative Theory

- Introduce a plausible alternative theory;
- ensure that the anomalous data (discrepant data) is credible; and,
- ensure that such an alternative theory is easily comprehensible to the audience.

C. Introduce the Anomalous Data

- Ensure that the anomalous data is credible and familiar;
- avoid using any ambiguous data; and,
- when necessary, encourage the use of multiple lines of information (data).

D. Influence Processing Strategies

Encourage students to pursue deep processing of available information when they are being presented with the anomalous data. (To ensure 'deep processing' of information, we recommend the use of appropriate thinking and reasoning skills — skills that are consistent with the development of scientific and logical reasoning strategies.)

Concluding Remarks

Our intention in this article was to highlight the heuristic value of using discrepant events as an avenue to promoting inquiry-oriented learning in the science classroom. Even though it is obvious that examples of discrepant events cannot be developed for every topic or scientific principle, teachers should remember that the event is used as an incentive to student involvement.

We hope science teachers will enjoy using discrepant event examples in the classroom. Teachers could go a step further by motivating students to work with their peers to research discrepant events that appeal to their curiosity, develop practical skills of report writing and present the information to the public.

In closing, we particularly welcome both teachers and students to share with us their discrepant event examples. Let us know what works for you, particularly if and when you modify our suggestions. For those of you already using discrepant events, we would enjoy learning of your ideas. Please share them with us.

Girish Govindarajan is Assistant Professor of Science Education working on biology instruction. He received recognition in the ICASE-UNESCO 1991 edition of Who's Who in Science Education Around the World, for his professional contributions in biology and teacher education.

Emmett Wright is Professor of Science Education at Kansas State University, USA. He has written a popular manual of minds-on and hands-on scientific discrepant events and has been involved in developing exchange programmes with academic institutions in Russia and Central America.

Suggested Reading

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C A Chinn and W F Brewer. The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction. *Review of Educational Research*. 63 (1): 1–49. 1993.

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E L Wright and G Govindarajan. Discrepant event demonstrations. *The Science Teacher*. 62 (1): 25–28. 1995

E L Wright and G Govindarajan. Teaching with scientific conceptual discrepancies: Unlocking the mind to problem-solving using simple discrepant events to illustrate science concepts and principles. Manhattan, KS 66506: College of Education, Kansas State University, USA. 1996.

If readers wish to acquire any of the above references, please contact the first author.

Think it Over

This section of Resonance is meant to raise thought-provoking, interesting, or just plain brain teasing questions every month, and discuss answers a few months later. Readers are welcome to send in suggestions for such questions, solutions to questions already posed, comments on the solutions discussed in the journal, etc. to Resonance, Indian Academy of Sciences, Bangalore 560 080, with "Think It Over" written on the cover or card to help us sort the correspondence. Due to limitations of space, it may not be possible to use all the material received. However, the coordinators of this section (currently A Sitaram and R Nityananda) will try and select items which best illustrate various ideas and concepts, for inclusion in this section.

From : S K Ghoshal, Indian Institute of Science, Bangalore.

Discussion of question raised in ***Resonance***, Vol 1, No 4.

1 Self-Copying Program

Can you write a program in C which prints its own source code? How about writing such a program in other languages like Fortran? This is one solution that opens the file (the file can have any name) containing the source code and prints out the program character by character. The program has been verified to work correctly on a number of architectures, C compilers and operating systems.

/* This program, when compiled and executed, prints out its own source code */

```
#include <stdio.h>
main() {FILE *fp; int c; fp=fopen(__FILE__,"r"); if (fp=
= NULL){fprintf(stderr,"Unable to open% \n\n",__FILE_
_);exit(1);} while ((c=fgetc(fp)) !EOF) putchar(c);}
```

Figure 1: A C program that prints its own source code

2 To Switch, or not to Switch

From : Rajeeva L Karandikar, Indian Statistical Institute, Delhi

Discussion of question raised in *Resonance*, Vol 1, No 5.

You are a winner in the preliminary round of a TV game show and the host gives you a chance to win the super prize: a fancy car. You are shown three doors numbered 1, 2 and 3. Behind one of them is the car. You are asked to choose a door. If the chosen door is the one hiding the car, you win the prize.

You choose, say, door number 2. The host of the show then says: "First, let us see what is behind door number 1" He opens it and you see that the car is not there. Now he asks you: "Do you want to stay with your initial choice (number 2), or would you like to switch to door number 3?" What would you do?

Does this have a familiar ring to it? May be the 'Prisoner's dilemma' has the same logic.

Answer: As in the 'Prisoner's dilemma', we need to model the behaviour of the game show host before we can tell whether the player should switch or not.

If our model for the game show host is that he doesn't know the location of the car and he just picks one of the two remaining doors at random and opens it, then finding that the door so opened doesn't have the car behind it doesn't give any information intuitively - and thus it doesn't matter whether the player switches or not. To see this, let A denote the event "the car is behind the door chosen", B denote the event "the car is behind the door opened by the host" and C denote the event "the car is behind the third door". Then under the model made above, $P(A)=1/3$, $P(B)=1/3$ and $P(C)=1/3$. Further, writing D to be the complement of B, one has $P(A$ and $D)=1/3$, $P(C$ and $D)=1/3$ and hence $P(A|D)=1/2$; $P(C|D)=1/2$.

However, if one has seen the show in the past and has observed

that the game show host always gives the player this choice and always the door opened by him doesn't have the car behind it, then it is reasonable to assume that he knows where the car is and always opens a door which doesn't have the car behind it. In this case, the allocation of probabilities made above is not valid. Here again $P(A)=1/3$, and writing E as the complement of A, $P(E)=2/3$. A moment's reflection would convince the reader that the event that one gets the car by switching is the same as the event E! Thus one should switch and increase one's chance of winning the car.

So, in either of the cases considered above, one won't be worse off if one switches, and in the second case, one would indeed be much better off.

On the other hand, if one has observed in the past that the game show host didn't give the choice always to the player, and whenever he gave the choice, the car really was behind the door originally chosen by the player, then clearly one should never switch.

So the conclusion in this example is that the problem as stated doesn't have a single answer. In the language of mathematics, it is ill posed. To answer it, we must model the behaviour of the game show host. The model could be based on our past observations or on our intuition.

From : J V Shreyas, a II PUC student from Bangalore, sends us the following very interesting questions relating to the frictional forces on the wheels of a bicycle. These may help to enliven classroom discussions of otherwise dry topics.

? Which Direction Does the Frictional Force Act

Consider a bicycle moving from the West to East. What is the frictional force acting on each wheel, when

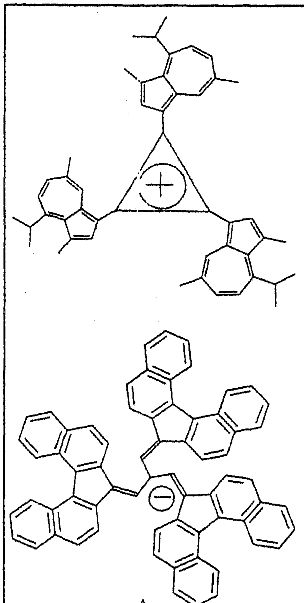
a) The cycle is being pedalled? and

b) When it is moving freely (without being pedalled)?

! Factors Stabilizing the Ionic Hydrocarbon, $C_{115}H_{90}$

Photon Rao,
Answer to the question posed in the March 1996 Issue of *Resonance*

The first example of an ionic hydrocarbon was mentioned in the 'Think It Over' section of *Resonance*, 1996, 3, pg 115. What factors prevent the formation of a C–C single bond between the carbocation and carbanion components of A?



A

There are both thermodynamic and kinetic reasons which let the compound remain ionic. The two ionic units are individually stabilized by delocalization. A cyclopropenium carbocation is a Hückel aromatic system. Further delocalization of the positive charge in the electron rich, non–benzenoid aromatic azulene moiety provides added stability to it. Similarly, the carbanion is highly delocalized, especially since the negative charge would make the cyclopentadienyl units aromatic. The substituents play another role to keep the ionic pieces apart. They are bulky and act as a shield preventing C–C bond formation.

Believe me, Papa! It is an OPTICAL ILLUSION !

ew Orbital Hybridization chemes for Metal Hydrides

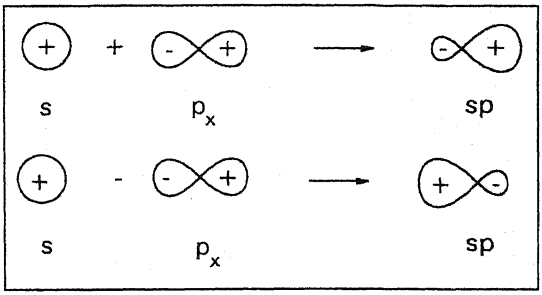
eping *p* Orbitals out of the cture

Chandrasekhar

e of the most widely applied concepts in nding theory is hybridization. The idea s introduced by Linus Pauling 65 years as a simple way of explaining shapes of lecules. Pauling considered combinans of atomic orbitals, rather than 'pure' *s* d *p* orbitals, to form bonds (and to hold e pairs of electrons). For example, an *s* d a *p* (say p_x) orbital can be combined in o ways: ($s + p_x$) and ($s - p_x$). It is easy to that these *sp* hybridized orbitals have e large lobe each (*Figure 1*). These are exnded along the +x and -x directions. cause of their spatial extension, these orals can overlap better than the pure *s* and orbitals. The bonds formed using hybrid bitals will therefore be stronger. Further, e bonds will have directional character. e preferred bond angle will be 180°. One n readily understand why acetylene is ear. In order to form two strong σ bonds, ch carbon atom is *sp* hybridized. The reaining *p* orbitals are used to form the nds of the molecule.

ing similar arguments, the tetrahedral ordination of saturated carbon and trigo-l planar geometry at olefinic centres can rationalized. The optimum way to form

***Figure 1** Shapes of sp hybridized orbitals.*



4 σ bonds is to use sp^3 hybridization. The 4 combinations have one large lobe along each corner of a tetrahedron. Similarly, 3σ bonds can be formed best using sp^2 hybrid orbitals, whose extended lobes make an angle of 120° to each other.

The idea is not restricted to organic molecules. More complex shapes encountered in inorganic systems can be explained using suitable hybridization schemes. For example, d^2sp^3 hybrid orbitals have lobes extending towards the corners of an octahedron. Similarly, square planar geometry is compatible with dsp^2 hybridization. The coordination geometries resulting from admixtures of *s*, *p* and *d* orbitals are summarised in *Table 1*.

***Table 1** Hybridization schemes and resulting geometries*

Orbitals used	Coordination Geometry
sp^3	Tetrahedral
sp^2	Trigonal planar
sp	Linear
d^2sp^3	Octahedral
dsp^2	Square Planar
dsp^3	Trigonal Bipyramidal

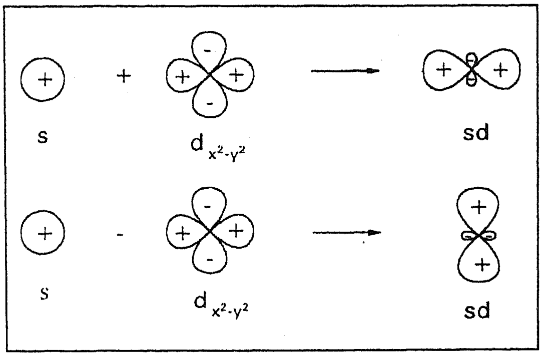
Although Pauling suggested hybridization schemes for all types of molecules, the idea is generally used in systems with 2- centre 2-electron bonds. These include the vast majority of molecules of interest to organic chemists. But for inorganic molecules, some extra rules are needed to derive the shapes. In one popular version, the relative magnitude of repulsions involving lone pairs and bond pairs, placed in hybrid orbitals, is considered (Valence Shell Electron Pair Repulsion Theory). In the extreme case of electron–deficient molecules, like boron hydrides, the additional factors to be taken into account become cumbersome. The hybridization idea is not even used as a starting point. Instead, alternative bonding models (Molecular Orbital correlation diagrams) are usually employed. Different horses for different courses!

It was therefore somewhat surprising to find a claim last year that the hybridization model represents the simplest way to 'make sense of the shapes of simple metal hydrides' (C. R. Landis, T. Cleveland and T. K. Firman, *Journal of American Chemical Society*, Vol. 117, 1859-1860, 1995). Geometry optimization using high level computational methods led to unusually complex shapes for transition metal hydrides and alkyls. For example, the minimum energy form of WH_6 was not octahedral. Several low symmetry forms were computed to have lower energy. In order to explain the unusual structures they obtained, the authors proposed a new set of hybridization schemes, using combinations of *s* and *d* orbitals, but leaving out *p* orbitals. Although *s*, *d* hybrids had been sporadically used before, Landis et al. were the first to provide systematic rules for using sd^n hybridization.

The procedure for deriving the shape of a metal hydride is as follows. (a) Count the number of valence electrons in the metal and the electrons provided by the ligands. For WH_6, the total is 12. (b) Place the *n* bonding electron pairs in sd^{n-1} hybrid orbitals. Since there are 6 bonds in WH_6, the appropriate set is sd^5 hybrid orbitals. The shape of the molecule is determined from the angular characteristics of these hybrids. (There are two more rules which are not relevant for WH_6. For the sake of completeness, they are: (c) Additional electrons, if present, are placed in pure *d* orbitals as lone pairs. (d) If all *d* orbitals are used up, use multi-centre bonding. Back to the never-say-die approach of Pauling!)

It turns out that sd^n hybrids have peculiar directional character. For example, consider combinations from an *s* and a *d* orbital. Instead of getting a single extended lobe as in *sp* hybrid orbitals, two lobes get enlarged in the *sd* hybrids (*Figure 2*). Although only one of these lobes can be used for bonding, the hybrid orbital can still overlap better than a pure *s* or *d* orbital.

Figure 2 Shapes of sd hybridized orbitals.



Whichever pair of lobes is used, the resulting bond angle would be 90°

The presence of two extended lobes per sd^n hybrid has an interesting consequence. If θ is one of the preferred bond angles, (180°– θ) is also equally favoured. Landis et al. have worked out the preferred bond angles (rounded to the nearest degree) to be as follows:

sd^2:90°; sd^3: 71° and 109°; sd^4: 66° and 114°; sd^5: 63° and 117°.

With the idealized bond angles, four geometries can be constructed for the supposedly sd^5 hybridized WH_6 molecule. Two have C_{3v} symmetry and two more have C_{5v} symmetry (*Figure 3*). All were calculated to be fairly close to each other in energy.

Figure 3 The four possible geometries of WH_6 using sd^5 hybridization on the metal. The first C_{3v} structure is related to a distorted trigonal prism; the top half is compressed, while the bottom half is expanded. The second C_{3v} form is a distorted octahedron; the two 3-fold units are staggered. The five-fold symmetric structures resemble normal and 'inverted' umbrellas. Note that in two of the four structures, all the bonds point to the same half of a hemisphere around the metal.

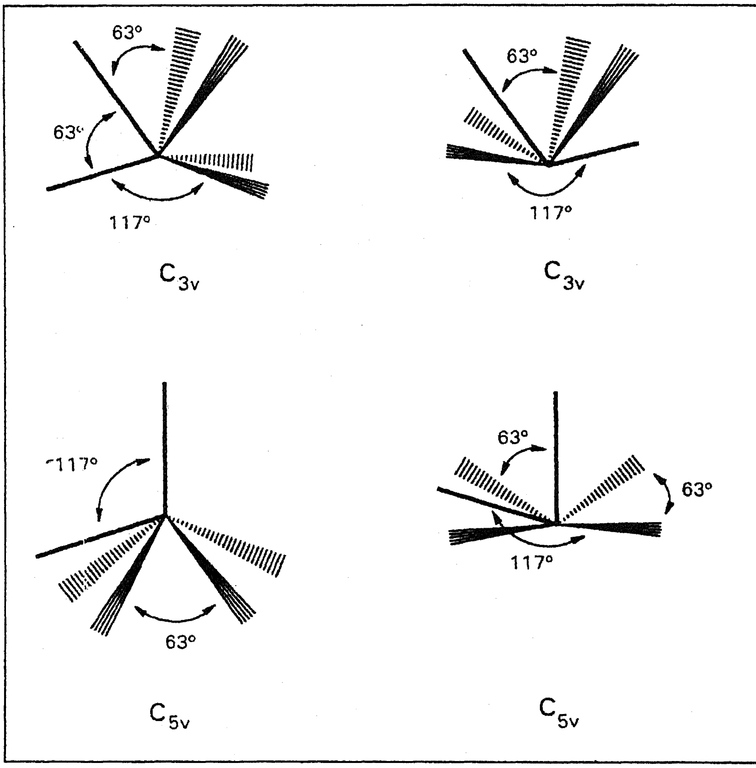
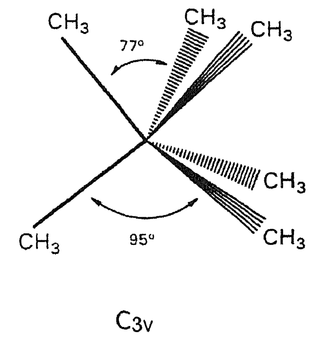


Figure 4. The observed structure of $W(CH_3)_6$.



Oblivious of this work, V Pfennig and K Seppelt were carrying out a difficult experiment with hexamethyltungsten, $W(CH_3)_6$. They managed to recrystallize the thermally unstable (explosive!) substance from acetone at –90°C and determined the X-ray structure at –163°C (*Science*, Vol. 271, 626–628, 1996). The molecule was found to have a shape derived from a distorted trigonal prism (*Figure 4*). The authors justified the preference using a molecular orbital correlation diagram connecting an octahedron, trigonal prism and a C_{3v} distorted form. The filled orbitals in this d^0 system were shown to be stabilized in the C_{3v} form to a greater extent.

Landis et al. pointed out (*Science*, vol. 272, 182, 1996) that the observed non-octahedral structure of $W(CH_3)_6$ is the same as the one they had predicted a year earlier. The form with the least steric repulsion between the methyl groups would be the C_{3v} structure derived from the trigonal prism. The interactions alter the bond angles to 77° and 95°, instead of the idealized values of 63° and 117°. Landis et al. had anticipated these changes too in their original work.

Seppelt was quick to acknowledge the simplicity and accuracy of the sd^n hybridization model for metal hydrides and alkyls. He has also graciously stressed that the prediction of Landis et al. was made before and without prior knowledge of the crystallographic work.

Interested readers may find many more predictions of shapes of species like NbH5, TcH_5, PdH_3^-, RhH_4^-, PtH_4^{2-}, FeH_6^{4-}, etc., in the publication of Landis and coworkers.

One may wonder why *p* orbitals do not seem to be important in bonding in these systems. Hybridization leads to stabilization only if the promotion energy is relatively small. It therefore appears that the *np* orbitals are considerably higher in energy than the (n–1)*d* and *ns* orbitals. This may be generally true in the lower right half of the transition metal series, especially if the effective charge on the metal is very low. There is also no metal-ligand π bonding in the hydrides and alkyls. Under these special circumstances, sd^n hybridization may be the preferred mode of bonding.

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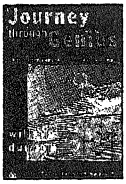
The Great Theorems of Mathematics

A Mathematical Journey

K R S Sastry



Journey Through Genius
William Dunham
Penguin books, 1991,
vii+300 pages, soft cover,
Rs.310.

The author presents a personal chronological selection of twelve great theorems from Hippocrates, Euclid, Archimedes, Heron, Cardano, Newton, Johann Bernoulli, Euler and Cantor.

A general reader needs to develop an appreciation of mathematics; a student of mathematics needs to develop a mathematical culture by reading books that reveal the exciting, inspirational, and human aspects of mathematics. This is quite different from what the student learns in classroom lectures. Bill Dunham's *Journey Through Genius* succeeds in serving these purposes and provides a better vision of mathematics for the reader. The author presents a personal chronological selection of twelve great theorems (and several not so great ones) from Hippocrates, Euclid, Archimedes, Heron, Cardano, Newton, Johann Bernoulli, Euler and Cantor. He says in the preface of the book that he wants to reach a wide audience. So he sets the historical scene and provides the necessary mathematical background before presenting each great theorem. Next he presents the original proof of that great theorem using modern terminology. He faithfully follows that scheme throughout the *Journey*.

A college mathematics student can easily follow Dunham's exposition; a college lecturer can use it as a source book for lectures – either in the classroom or on more popular occasions. The presentation is clear and the style engaging. In Chapter 1 he tells us the way Hippocrates succeeded in the quadrature of a particular lune (finding the area of the region enclosed by two circular arcs). But the world had to wait for Archimedes and some two hundred years for the quadrature of the circle. This is discussed in Chapter 4. You are compelled to admire the simplicity and the ingenuity in Euclid's proof of the infinitude of the primes or Georg Cantor's proof of his theorems. Again, you are compelled to notice the creativity and the skill that went into Euler's evaluation of the infinite series $1+1/4+1/9+.....$. In Chapter 6 you will learn of the role played by the mathematical challenges of the time to solve the general cubic and the general quartic in radicals. Heron's proof that the area of the

A college mathematics student can easily follow Dunham's exposition; a college lecturer can use it as a source book for lectures

triangle with side lengths a, b, c and semi-perimeter s is $\Delta = \sqrt{s(s-a)(s-b)(s-c)}$ is awesome! (Here Heron misses the significance of the construction of a point he started with. A short geometric proof based on the knowledge of geometry of his time is possible (*Samasya*, Vol.3, No.2, 1196)). Pages 53–60 contain a discussion of Euclid's parallel postulate. Dunham tells us how Gauss, Bolyai, Lobachevski, and Riemann arrived at two different geometries differing from Euclid's when the parallel postulate was replaced by two other possibilities. Later on in pages 277–278 he tells us that a similar situation developed when Cantor introduced transfinite numbers.

On the nonmathematical side you will admire the various tactics employed by Archimedes to fight the attacking Roman army. Dunham exhibits remarkable ability, be it in the portrayal of the many–sided personality of Cardano, the calculus controversy involving Newton and Leibniz or the tragic events in Georg Cantor's life. Scholars differ while giving historical accounts and you have to read various scholars before you arrive at your conclusions. Dunham has provided, not a long, but a useful list of references. The student reader is strongly advised to read as many of these as possible.

Since the publication of the *Journey*, Dunham has delivered invited lectures at a number of places. He was interviewed on Australian Radio (Dunham is a professor of mathematics in the USA). The Mathematical Association of America has just released a video tape in which he talks about mathematical contributions of ancient Babylonians, Egyptians, and Greeks. Also, the references below for a list of recently published journal articles on related themes.

For example, a first year college student comments on the *Journey*: "the historical and the biographical details make an interesting reading... the proofs are easy to follow." *Read the Journey, ask your friends to read it, urge the libraries to have a copy of it.*

Finally a request to the publisher: Reduce the price of the book for the purchaser in India!

Suggested Reading

Hazel Perfect, Georg Cantor. 1845-1918 He Transposed Mathematics into a New Key. *Mathematical Spectrum.* **27:25-28. 1994-5.**

G Hossein Behforooz. Thinning out the Harmonic Series. *Mathematics Magazine.* **68:289-293. 1995.**

Lester H Lange. Did Plutarch Get Archimedes' Wishes Right? *College Mathematics Journal.* **26:199-204. 1995.**

Semyon Gindking, The Great Art: The Controversial Origins of "Cardano's Formula". *Quantum.* **May-June:40-45. 1995.**

Vladimir Tikhomirov, Georg Cantor. *Quantum.* **Nov-Dec:48-52. 1995**

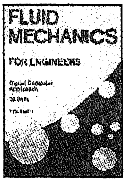
Samasya. **3:2 (to appear in Sept.1996).**

K R S Sastry, 2943 Yelepet, Doddballapur 561 203

Fundamental Fluid Mechanics

Good Text Book Material

V H Arakeri



Fluid Mechanics for Engineers
P N Chatterjee
MacMillan India Limited
Vol. 1, pp. 367. Rs.143
Vol.2, pp.306. Rs.130

Fluid Mechanics for Engineers in two volumes by P N Chatterjee contains standard material for a first level course in fluid mechanics for Civil, Mechanical, Aeronautical and Chemical Engineering students. It is however not suitable for Applied Science students like those majoring in Physics or Mathematics and is not a good reference book for practising engineers. The first volume covers material suitable for a beginner's course; whereas the second volume deals with more advanced topics, but at an elementary level. Considering both volumes, the coverage is quite exhaustive and there are two chapters on nonuniform flow in open channels and unsteady flow in conduits, surge and waterhammer which are not commonly found in standard text books on fluid mechanics. The latter topics should be of special interest to civil engineering students.

Both the volumes are written systematically, clearly with stress on fundamental principles. In my opinion, the presentation

Both the volumes are written systematically, clearly with stress on fundamental principles.

is of very good quality; in particular, the examples solved should enable students to grasp the essentials quite well. The problems at the end of each chapter, are however of routine nature and could have been accompanied with more illustrations.

Some of the weak points in the two volumes are: there is no justification for including digital computer application on the cover page, in chapter 5 on application of momentum equation the fact that the control volume in each problem has to be chosen judiciously has not been stressed. It is important to choose the control volume boundaries where the streamlines are straight and parallel; in fact, the author has chosen the wrong control volume in Figures 8, 7 to analyse the flow through a Borda's mouthpiece. Similarly, the use of tables in solving problems in compressible flow has not been encouraged; this is essential since many of the compressible flow relations have multiple solutions. It would also have been useful to demonstrate the application of unsteady Bernoulli equation with simple examples. There is a large

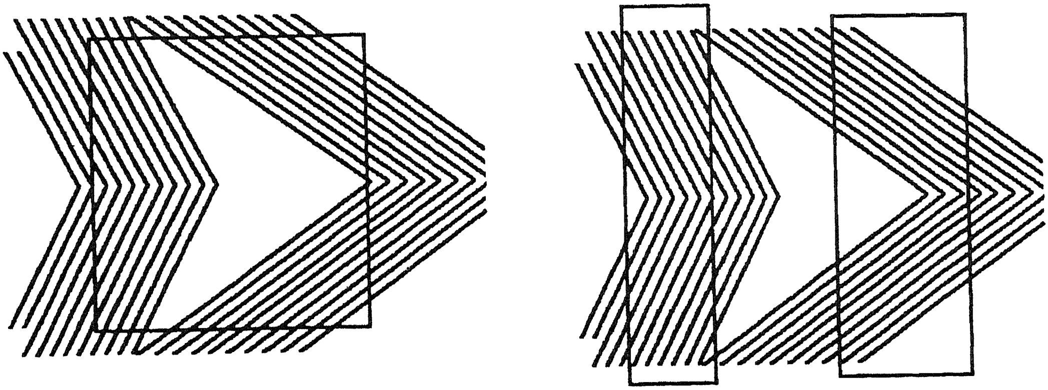
On the whole, I strongly recommend these as text books for undergraduate engineering students at the beginner's level.

number of typographical errors. The shortcomings noted are, however, minor compared to the positive aspects.

On the whole, I strongly recommend these as text books for undergraduate engineering students at the beginners' level. They could be used as reference material by postgraduate students who would like to brush up on their fundamentals. The first seven chapters of Vol.1 can form the core material and the other chapters can be included depending upon the time and taste of the instructor for a particular course. Considering the material covered the cost of the books is quite reasonable.

V H Arakeri is with Department of Mechanical Engineering, Indian Institute of Science, Bangalore 560 012, India.

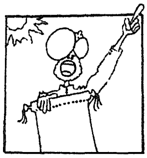
Zolliner – Poggendorff Illusion



The square on the left and the rectangle in the middle exhibit a combination of two different illusions. Some of their sides appear bent due to cross hatching. This is Zolliner's illusion. Also some of the lines of the cross hatch appear broken and discontinuous at the edges of these figures. This is Poggendorff's illusion. Interestingly both these illusions are nearly absent in the rectangle on the right.

— G S Ranganath

Information and Announcements



India Wins 1 Gold, 3 Silver and 1 Bronze Medals at the 37th IMO

The 37th International Mathematical Olympiad recently concluded at Mumbai, India. 424 students from 75 countries participated in the event. Romania, USA and Hungary were ranked at the first 3 positions. India was ranked 14 in its overall performance.

Ciprian Manolescu of Romania performed brilliantly. He was the only student who secured the full point 42. The following are the results of the Indian participants:

1	Ajay C Ramdoss, Bangalore	Gold
2	Kaustubh P Deshmukh, Pune	Silver
3	Ashish Mishra, Ranchi	Silver
4	Rishi Raj, Ranchi	Silver
5	K Gopalakrishnan, Madras	Bronze
6	Ashish Kumar Singh, Kanpur	No medal

Ajay is a student of National Public School, Rajajinagar, Bangalore. Rishi Raj, the youngest participant from India is a student of the 10th standard.

The six problems which appeared in the 37th IMO are reproduced below. (The name in the brackets refers to the country which proposed the problem.) Problem 5 turned out to be the toughest; only six of the 424 participants solved it fully.

First day (10 July, 1996)

1. Let $ABCD$ be a rectangular board with $|AB| = 20$, $|BC| = 12$. The board is divided into 20×12 unit squares. Let r be a given positive integer. A coin can be moved from one square to another if and only if the distance between the centres of the two squares is $\sqrt{r}$. The task is to find a sequence of moves taking the coin from the square

which has A as a vertex to the square which has B as a vertex.

(a) Show that the task cannot be done if r is divisible by 2 or 3.

(b) Prove that the task can be done if $r = 73$.

(c) Can the task be done when $r = 97$?
(Finland)

2. Let P be a point inside triangle ABC such that

$$\angle APB - \angle ACB = \angle APC - \angle ABC.$$

Let D, E be the incentres of triangles APB, APC respectively. Show that AP, BD and CE meet at a point.
(Canada)

3. Let $S = \{0, 1, 2, 3, \ldots\}$ be the set of non-negative integers. Find all functions f defined on S and taking their values in S such that

$$f(m + f(n)) = f(f(m)) + f(n),$$

for all $m, n \in S$.
(Romania)

Second day (11 July, 1996)

4. The positive integers a and b are such that the numbers $15a + 16b$ and $16a - 15b$ are both squares of positive integers. Find the least possible value that can be taken by the minimum of these two squares.
(Russia)

5. Let $ABCDEF$ be a convex hexagon such that AB is parallel to ED, BC is parallel to FE and CD is parallel to AF. Let R_A, R_C, R_E denote the circumradii of triangles FAB, BCD, DEF respectively, and let p denote the perimeter of the hexagon. Prove that

$$R_A + R_C + R_E \geq \frac{p}{2}.$$

(Armenia)

6. Let n, p, q be positive integers with $n > p + q$. Let $x_0, x_1, \ldots, x_n$ be integers satisfying the following conditions:

(a) $x_0 = x_n = 0$;

(b) for each integer i with $1 \leq i \leq n$, either $x_i - x_{i-1} = p$ or $x_i - x_{i-1} = -q$. Show that there exists a pair (i, j) of indices with $i < j$ and $(i, j) \neq (0, n)$ such that $x_i = x_j$.
(France)

Acknowledgements

Resonance gratefully acknowledges the help received from the following individuals:

T Krishnan, V Pati, Jayant Rao and A G Samuelson.

Errata

Resonance, Vol 1, No.6 (1996)

Page 20: In the section on microwave background the temperature in the fourth line should read 2.735 K.

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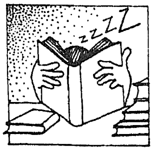
Books Received



The Language of the Genes
Steve Jones
Flamingo
1993, Rs.243.00

A Darwin Selection
Mark Ridley
Fontana Press
1994, Rs.243.00

In the Beginning - The Birth of the Living Universe
John Gribbin
Little, Brown & Co.
1993, Rs.458.00

Late Night Thoughts of Listening to Mahler's Ninth Symphony
Lewis Thomas
Penguin Books
1983, Rs.309.00

The Youngest Science - Notes of a Medicine Watcher
Lewis Thomas
Penguin Books
1983, Rs.336.00

The Lines of a Cell - Notes of a Biology Watcher
Lewis Thomas
Penguin Books
1974, Rs.309.00

Safety Evaluation of Environmental Chemicals
T S S Dikshith
New Age International
1996, Rs.350.00

Eclipse (translated from Kannada by H R Madhusudan)
B S Shailaja
1996, Rs.30.00

Matrices and Tensors in Physics
A W Joshi
1996, Rs.135.00

Vedic Astronomy
P V Holay
Baba Saheb Apte Smarak Samitee
1996, Rs.60.00

Horizons of Physics – Volume II
Narendra Nath and A W Joshi
New Age International
1996, Rs.600.00

Tradition, Science and Society
S Balachandra Rao
Navakarnataka
1990, Rs.15.00

Guidelines for Authors

Resonance - *journal of science education* is primarily targeted to undergraduate students and teachers. The journal invites contributions in various branches of science and emphasizes a lucid style that will attract readers from diverse backgrounds. A helpful general rule is that at least the first one third of the article should be readily understood by a general audience.

Articles on topics in the undergraduate curriculum, especially those which students often consider difficult to understand, new classroom experiments, emerging techniques and ideas and innovative procedures for teaching specific concepts are particularly welcome. The submitted contributions should not have appeared elsewhere.

Manuscripts should be submitted in *duplicate* to any of the editors. Authors having access to a PC are encouraged to submit an ASCII version on a floppy diskette. If necessary the editors may edit the manuscript substantially in order to maintain uniformity of presentation and to enhance readability. Illustrations and other material if reproduced, must be properly credited; it is the author's responsibility to obtain permission of reproduction (copies of letters of permission should be sent). In case of difficulty, please contact the editors.

Title Authors are encouraged to provide a 4-7 word title and a 4-10 word sub-title. One of these should be a precise technical description of the contents of the article, while the other must attract the general readers' attention.

Author(s) The author's name and mailing address should be provided. A photograph and a brief (in less than 100 words) biographical sketch may be added. Inclusion of phone and fax numbers and e-mail address would help in expediting the processing of manuscripts.

Summary and Brief Provide a 2 to 4 sentence summary, and preferably a one sentence brief for the contents page.

Style and Contents Use simple English. Keep the sentences short. Break up the text into logical units, with readily understandable headings for each. Do not use multiple sub sections. Articles should generally be 1000-2000 words long.

Illustrations Use figures, charts and schemes liberally. A few colour illustrations may be useful. Try to use good quality computer generated images, with neatly labelled axes, clear labels, fonts and shades. Figure captions must be written with care and in some detail. Key features of the illustration may be pointed out in the caption.

Boxes Highlights, summaries, biographical and historical notes and margin notes presented at a level different from the main body of the text and which nevertheless enhance the interest of the main theme can be placed as boxed items. These would be printed in a different typeface. Such a boxed item should fit in a printed page and not exceed 250 words.

Suggested Reading Avoid technical references. If some citations are necessary, mention these as part of the text. A list of suggested readings may be included at the end.

Layout It is preferable to place all the boxes, illustrations and their captions after the main text of the article. The suggested location of the boxes and figures in the printed version may be marked in the text. In the printed version, the main text will occupy two-thirds of each page. The remaining large margin space will be used to highlight the contents of key paragraphs, for figure captions, or perhaps even for small figures. The space is to be used imaginatively to draw attention to the article. Although the editors will attempt to prepare these entries, authors are encouraged to make suitable suggestions and provide them as an annexure.

Book Reviews

The following types of books will be reviewed : (1) text books in subjects of interest to the journal; (2) general books in science brought to the attention of students/teachers; (3) well-known classics; (4) books on educational methods. Books reviewed should generally be affordable to students/teachers (price range Rs.50 to 300).

New books will get preference in review. A list of books received by the academy office will be circulated among the editors who will then decide which ones are to be listed and which to be reviewed.

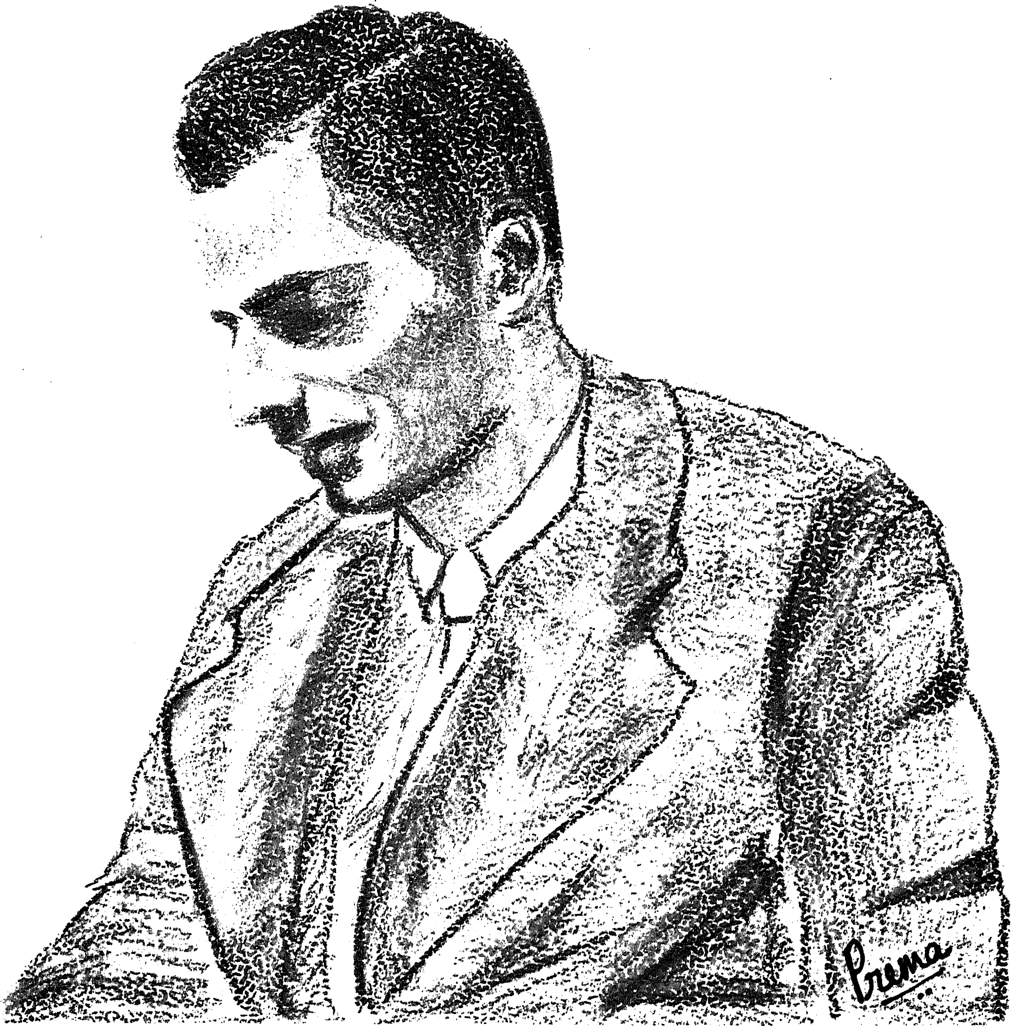
"It is difficult to communicate the grandeur of Harish-Chandra's achievements and I have not tried to do so. The theory he created still stands - if I may be excused a clumsy simile - like a Gothic cathedral, heavily buttressed below but, in spite of its great weight, light and soaring in its upper reaches, coming as close to heaven as mathematics can. Harish, who was of a spiritual, even religious, cast and who liked to express himself in metaphors, vivid and compelling, did see, I believe, mathematics as mediating between man and what one can only call God. Occasionally, on a stroll after a seminar, usually towards evening, he would express his feelings, his fine hands slightly upraised, his eyes intent on the distant sky; but he saw as his task not to bring men closer to God but God closer to men. For those who can understand his work and who accept that God has a mathematical side, he accomplished it."

R P Langlands — Harish-Chandra: In Memoriam, Princeton, April 23, 1984.

"In the austere simplicity and uncompromising nature of his approach to life, in his preference for solitary and profound reflection, and in his awesome capacity to discern and persevere after distant goals, he resembled the legendary figures from his country's ancient past. And like them, he came to be quite detached about his achievements as well as his failures. This detachment was not a false modesty; like many great men Harish-Chandra was fully conscious of his gifts and what he could do with them. It was rather a deeper humility, whose origin lay in a conviction that science was a collective endeavour and that any life is but a fragment in a larger fabric."

V S Varadarajan — Harish-Chandra: In Memoriam, Princeton, April 23, 1984.

ISSN 0971-8044



Harish-Chandra
1923-1983